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ENHANCING THE QUALITY OF
U.S. GRAIN
FOR INTERNATIONAL TRADE

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

J952-10

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Foreword

American agriculture, long the sector of the economy considered the most productive and competitive in the world, began to show signs of declining international competitiveness in the early 1980s. Many reasons have been given for this, including the problems of the quality of U.S. grain. The quality issue is receiving renewed attention in the current world buyers' market for grain. Some are concerned that as the influence of important economic variables such as the strength of the dollar and the extent of agricultural price support cause U.S. exports to become more price-competitive, opportunities to increase exports may be hampered by buyers' qualms about U.S. grain quality.

Complaints of overseas buyers about low-quality U.S. grain receive widespread attention. Buyers protest that they receive dirty, molded, or infested grain, or that characteristics contracted for, such as a certain protein level, were not met. Exporters argue that foreign buyers are using quality complaints to bargain for lower prices. Farmers and many Members of Congress point to loss of market share to prove the importance of quality. The problems—real or perceived—have persisted for many years, and neither industry response nor congressional actions to date provide a satisfactory answer or reassure U.S. customers.

During debate on the Food Security Act of 1985, the issue of the quality of U.S. grain was again raised. It became apparent that insufficient information was available to make wise decisions. Congress then amended the act and directed the Office of Technology Assessment to conduct a comprehensive study of the technologies, institutions, and policies that affect U.S. grain quality and to prepare a comparative analysis of the grain quality systems of major export competitors of the United States. The study was also requested by the House Committee on Agriculture and the Joint Economic Committee.

This report is one of two in that assessment. It focuses on the U.S. grain system and possible changes within that system to enhance grain quality. A second report, *Grain Quality in International Trade: A Comparison of Major U.S. Competitors*, provides OTA's analysis of the grain quality systems of other major exporters.

OTA greatly appreciates the contribution of the advisory panel, authors of technical background papers, the many industry associations, and other advisors and reviewers who assisted OTA from the public and private sector. Their guidance and comments helped develop a comprehensive study. As with all OTA studies, however, the content of this report is the sole responsibility of OTA.

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Chapter 1

Summary

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Chapter 1

Summary

More competitors exist in the international grain market now than ever before, and grain quality has become an extremely important competitive factor. In a mere decade, growth in grain suppliers has been phenomenal. In the 1970s, one-third of the world supplied grain to two-thirds of the world's people. Today, the reverse is true: two-thirds of the world supplies grain to the other third. This competitive environment has made foreign buyers increasingly sensitive about the quality of grain they receive.

During the debate on the Food Security Act of 1985, many Members of Congress expressed concern about the quality of U.S. grain exports. Grain elevator operators and export traders were accused of adultering loads of grain shipped to foreign buyers; these allegations were supported by a sharp increase in foreign complaints about quality. Grain traders and handlers maintained that they have been shipping grain according to specifications, and that most complaints were motivated by buyers' desires to obtain a higher grade of grain at a lower price.

The debate often focused on the adequacy of today's grain standards, developed over 70 years ago. Critics argue that the standards themselves are to blame for customer complaints. They claim that standards have not kept pace with the changing world marketplace and are frequently misunderstood by foreign buyers.

By focusing on standards, those debating about U.S. grain quality are seeing only part of the picture. Improving quality—or even the perception of quality—will be much more complicated than tinkering with the criteria for standards. Grain is vulnerable to quality deterioration at virtually every stage of production and marketing. Before changes can be contemplated, full understanding is needed of the complex, interrelated system of:

- developing varieties of grain,
- producing grain,
- harvesting grain,
- storing grain,
- handling grain, and
- testing grain.

Understanding these relationships is the main goal of this assessment.

First, it is important to clarify what is meant by grain quality. Webster defines quality as an essential character, a degree of excellence, or a distinguishing attribute. In grain, such a definition has come to mean a variety of things—being free of foreign material, not cracked or spoiled, or having the proper characteristics for a particular end use. No one definition of quality as it relates to grain has been accepted.

For the purpose of this assessment, quality is defined in terms of physical, sanitary, and intrinsic characteristics.

- *Physical quality* characteristics are associated with outward visible appearance of the kernel or measurement of the kernel. Included are kernel size, shape and color, moisture, damage, and density.
- *Sanitary quality* characteristics refer to the cleanliness of the grain. They include the presence of foreign material, dust, broken grain, rodent excreta, insects, residues, fungal infection, and nonmillable materials. These are essentially characteristics that detract from overall grain value.
- *Intrinsic quality* characteristics are critical to the end use of the grain. They are nonvisual and can only be determined by analytical tests. In wheat, for example, such characteristics refer to protein, ash, and gluten content. The characteristics depend on the grain and the end use within a grade.

MAJOR FINDINGS

The U.S. grain marketing system has a number of important characteristics. Handling (including exporting) and transport industries are highly competitive and there is relatively limited government intervention in the system. **One key principle throughout the U.S. system is that of self-selection.** Producers plant varieties perceived to be in their best interest; users (domestic and importers) specify and purchase certain qualities that are in their interest, given a range of alternatives and prices; handlers and exporters condition and move grain in their own interest. Each decision is based on the sovereignty of the individual decisionmaker, and takes into account incentives and disincentives reflected in market premiums and discounts for quality characteristics.

Fundamental Advantages of the U.S. Grain System

An important component of this study was a comparison of the U.S. grain system with the systems in other exporting countries. OTA collected information on production and distribution in Canada and sent study teams to Argentina, Brazil, France, and Australia to document their systems. **Five fundamental advantages of the U.S. marketing system are apparent: efficiency, productivity growth, wide range of qualities, the grading and inspection system, and market-determined premiums and discounts.**

Efficiency

The U.S. marketing system performs a number of complex functions—it assembles, handles, conditions, and allocates different qualities to domestic buyers in many locations and for export from a multitude of ports. Indeed, given the quantity produced, the many differences in qualities at different locations, and numerous locations of end-users and ports, the U.S. marketing system is more complex and performs more challenging functions than the marketing system of any other exporter. Yet the efficiency of the U.S. grain handling and transport system exceeds that of nearly all other countries, assuring lower marketing margins and higher prices to producers.

Productivity Growth

Plant breeding in the United States is relatively unfettered, compared with other countries, in terms of regulations over variety development and release. Ultimate success of varieties is determined by the market for seed stocks. Producers make choices in response to market incentives. Where comparisons are appropriate (i.e., in wheat), productivity growth as measured by yield exceeds that of most other exporters, with the exception of France. Productivity differences are affected by a multitude of factors including environment, soils, other inputs, relative prices, institutions, and policies. Thus, it is impossible to attribute yield differences to the institutional environment affecting varieties, but growth rates are influenced by variety release procedures.

A Wide Range of Qualities

No other country can offer such a wide range of intrinsic differences in grains to customers. This is obvious given the class differences in wheat, which is facilitated by production regions of differing environments and soils. Also, a wider range of physical and sanitary qualities exists in the United States than elsewhere. This is an advantage in the sense that more alternatives are available to buyers, some at lower costs, but it may be viewed as an externality in the sense that reputation is affected. The uniformity problem (discussed later) is a direct result of the multitude of qualities available. In addition, given such an unfettered system, importers need a certain amount of expertise to benefit fully from the wide range of qualities.

Grading and Inspection System

The U.S. grading and inspection system provides grade determination by an independent agency (i.e., one not having financial stakes in the transaction). Factors and limits in factors in the grade standards are relatively stable across crop years (i.e., the definition of No. 2 corn does not change from year to year). Similarly, the definition of No. 2 Hard Red Winter wheat does not change, although intrinsic differences not measured in the standards may change. This is not necessarily the case in other countries. Major changes to the U.S. system cannot be implemented in less than a year after they are promulgated. Some other exporters adjust factor limits with each crop year.

Market-Determined Premiums and Discounts

Premiums and discounts and/or regulations in all countries are used to provide quality incentives to market participants. **Those established in the United States are via the interaction of supply and demand for measurable quality characteristics,** i.e., the market for quality characteristics. Consequently, U.S. values perhaps reflect true values better than do premiums and discounts administered in several other exporting countries. A notable exception is France. Efficient determination of price differentials is important because they essentially allocate grain across end-users and provide signals throughout the production and marketing system. Through these differentials the system responds to market needs.

Competitors' Policies

The institutions, policies, and trading practices in the marketing system of the major grain exporting countries differ considerably. The extent of market intervention varies from highly regulated throughout (e.g., Australia and Canada), to partial, or no regulation. Differences exist in procedures for seed variety development and release, the use of variety identification in the marketing system, and the use of grain receival standards (table 1-1). **In addition, a number of other countries address grain quality problems as part of an integrated agricultural policy.** Major foreign wheat exporters have more extensive controls at first point of sale than U.S. exporters. Wheat from other countries is probably preferred over comparably priced U.S. wheats due to these mechanisms.

The policy and institutional structure of the U.S. grain system provides the framework for various grain-handling practices. **Technologies for producing and handling grain are quite similar among competing countries.** The main difference is that the United States is slightly more efficient in using these technologies. But points in the marketing channel at which they are used differ.

A case in point is cleaning. Outside the United States, most exporters clean grain at the first point of receipt. Canada and Australia are two exceptions, although for different reasons. Canada, however, is studying the economic feasibility of cleaning grain in the country versus at export and will probably change. Australian farmers deliver grain that does not need to be cleaned, unlike the situation in the United States. Basically, no economic incentive exists to clean grain at the first point of receipt in the United States.

The other major handling practice in which the United States differs from other exporters is blending. Blending U.S. grain over wide ranges of quality to create a uniform product for sale is necessitated by the lack of any minimum receival standard. Blending exists outside the United States but not to the same extent. In other countries it is done over very narrow ranges in quality. These exporters basically have grain of uniform quality moving throughout the system. The U.S. system lacks uniformity in quality throughout the market channel. At export, grain is blended in an attempt to produce a uniform quality that meets buyers' specifications. The OTA survey of foreign and domestic buyers of U.S. grain clearly indicated that lack of uniformity between shipments is the buyers' biggest complaint.

Problem Areas

Genetics and Variety Release

Genetically, yield and important intrinsic quality characteristics are often inversely re-

Table 1-1.—Comparison of Institutions and Policies Affecting Grain Quality of Major Grain-Exporting Countries

Activity/Policy	United States	Argentina	Brazil	France	Canada	Australia
Seed variety control	No State or Federal control. Release of varieties influenced to some extent by land-grant universities. Largely the market determines adoption of varieties.	Committee of government and industry must approve agronomic properties. Quality factors of minor influence.	Committee with broad representation directs research and approves varieties. Quality is potential criterion but not currently effective.	Formal mechanism exists that regulates release of varieties based on agronomic and quality criteria.	Formal mechanism used to license new varieties. Agronomic and quality criteria given equal weight in testing new varieties.	Formal mechanism followed as a prerequisite for release of varieties. Quality and agronomic criteria are used.
Grain receival standards	None. All types of quality are accepted with appropriate discounts for low-quality grain.	Grain not meeting a specified minimum quality (Condition Camara) is rejected at first point of sale.	Soybeans not meeting a minimum quality are rejected at first point of sale.	Grain not meeting export contract specifications can be rejected by surveying company or receiving elevator.	Developed eight grades for CWRS to differentiate quality. Lowest grade goes to feed market.	Wheat must meet minimum quality standards. If not it is allocated to feed market.
Marketing by variety	No mechanism exists for variety identification.	Variety is not identified in marketing channel.	Variety is not identified in marketing channel.	Very common. Variety often specified in wheat contracts.	Licensed grain must be visually distinguishable.	Very common-use variety control scheme to facilitate segregation by classes.
Price	Loan rate is principal price policy. Includes premiums and discounts for major grains but has not been responsive to market conditions.	Government establishes minimum prices for farmers and exporters. Government also establishes premiums for high-quality grain.	Government establishes a minimum price prior to planting. It is adjusted during the crop year to account for inflation and political pressure.	Key policy is European Community intervention price, which includes premiums and discounts for quality factors. Lower qualities of wheat equated to feed values.	Initial producer price is the principal price policy. Separate prices established for each grade of grain. Lower qualities of wheat equated to feed values.	Guaranteed minimum price (GMP) is key price policy. It is established by class and provides differentials for quality. Lower qualities of wheat equated to feed values.
Farm Storage	Farm policy in past decade has encouraged extensive on-farm storage and inter-year storage.	Government policy through pricing does not encourage on-farm or inter-year storage.	No incentive for farmers to store on farm.	Farm policy through the Common Agricultural Policy (CAP) has not encouraged development of extensive on-farm storage. Also relatively limited inter-year storage due to CAP.	Producer deliveries are regulated to primary elevators via quotas. On-farm storage is substantial.	Use of GMP provides no incentive for delivery in post-harvest period, leading to minimal use of on-farm storage.

SOURCE: Office of Technology Assessment, 1989.

lated in each of the major grains. In the case of wheat, it is well recognized that yield and protein quantity are inversely related. In corn, the trade-off is between protein, starch, and yield; in soybeans, it is between protein and yield. Breeding programs generally aim to improve yield and disease resistance and to satisfy apparently desirable intrinsic quality goals.

In the case of corn, most breeders have always sought to increase yield and improve harvestability, with intrinsic quality not being a priority. **The potential for improving quality through genetics is quite high.** However, many quality factors are traits known to be influenced by many genes. This makes enhancing quality more difficult than altering a trait influenced by a small number of genes. The task is further complicated by the fact that genetic alteration of one trait frequently leads to undesirable changes in other plant traits.

New crop varieties require approximately 9 to 12 years for development and release. If there were a change in plant breeding program objectives in 1989, such as development of new varieties with enhanced quality factors, it could be the end of the century before these new varieties were commercially available.

The emphasis on yield in many cases is due to the fact that though intrinsic quality characteristics may be important, they are not measured in the market. Incentives to improve intrinsic quality characteristics therefore are not transmitted through the market as readily as those associated with agronomic characteristics, such as yield, disease resistance, and harvestability.

Individual breeders or their institutions can exercise tremendous discretion regarding release of varieties. This is tempered, however, by the market system, which determines the success of any release. Market efficiency requires measurement of relevant intrinsic quality characteristics, which is absent in many cases. For example, a variety with lower yield but an improved intrinsic characteristic (e.g., bake test) not measurable in the marketing system would fail to survive in the seed market. Variety release procedures as currently practiced are not applied uniformly across States (or firms, in the case of private breeding) or over time.

No effective national policy exists on variety release that would assure uniformity in application of release criteria. In the case of wheat, in which public breeding is more important, the State Agricultural Experiment Stations maintain variety release procedures. These are in turn guided by the Experiment Station Committee on Organization and Policy. However, since no legally binding procedures for controlling the release of varieties exist, individual States can and do vary from this policy. Thus the criteria for variety release may not be uniform across States or consistent over time. Ultimately a particular class of wheat, corn, or soybeans produced in different States may differ in intrinsic quality.

Technologies Affecting Quality

Grain is a living organism and as such is a perishable commodity with a finite shelf life. Drying, storing, handling, and transporting technologies cannot increase quality once the grain is harvested. Each technology is a self-sustaining operation, but the way each is used has an impact on the ability of the others to maintain quality. For example, if grain is harvested wet, not only will this lead to increased breakage during harvesting, but it means the grain must be dried. Improper drying can lead to more breakage and to nonuniform moisture content. Moisture content, moisture uniformity, and the amount of broken grain and fine material affects storability and can have an impact on the technologies used to maintain quality during storage. Therefore, decisions made at harvest, as well as at each step thereafter, affect the system's ability to maintain and deliver a quality product.

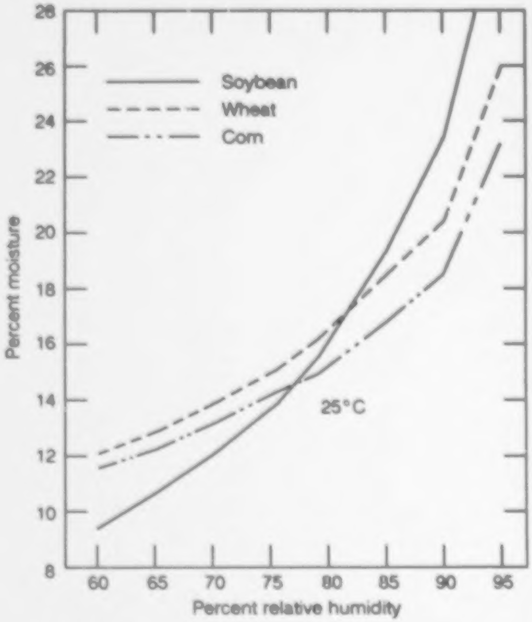
Moisture.—Moisture at harvest directly affects the amount of kernel damage produced through combining. Since cereal grains and oilseeds are harvested in the United States at moisture levels too high for long-term storage or even short-term storage and transportation, these commodities must be dried to acceptable moisture levels. Corn, which is harvested at 20 to 30 percent moisture, must be dried to 14 to 15 percent for safe storage. Wheat and soybean harvest moistures are substantially lower than corn, with safe storage levels marginally lower than harvest moisture. In certain regions of the United States, wheat and in some cases corn and soybeans dry naturally in the field.

The process of drying has a greater influence on grain quality than all other grain handling operations combined. If superior grain quality is to be produced, it is imperative to optimize the dryer type and its operation since half the corn crop is dried in continuous-flow, portable batch, and batch-in-bin dryers. Of particular concern is the increase in breakage of corn and soybeans and the decrease in milling quality of wheat from improper drying. Artificial drying of wheat and soybeans, however, is not frequently required.

The main dryer operating factors affecting grain quality are air temperature, grain velocity, and airflow rate. A dryer operator is able to adjust the first two on every dryer and, on some units, can adjust all three. Collectively, the three conditions determine the drying rate and maximum temperature of the grain being dried, and thus establish the quality of the dried lot.

At least 80 percent of the U.S. corn crop is dried on-farm. On-farm dryers fall into three categories—bin, non-bin, and combination dryers. **Bin dryers generally are low-capacity, low-temperature systems, able to produce excellent quality grain. Non-bin dryers, the most popular type in this country, are high-capacity, high-temperature systems that frequently overheat and overdry the grain, and thereby cause serious grain-quality deterioration.** Combination drying reaps the advantages of both systems (i.e., high capacity and high quality) but requires additional investment, and is logistically more complicated. **A switch by farmers from non-bin drying to combination drying would significantly improve U.S. corn quality.**

Figure 1-1.—Moisture, Temperature, and Relative Humidity Interactions



SOURCE: Office of Technology Assessment, 1989

Three classes of off-farm dryers are used—crossflow, concurrent-flow, and mixed-flow dryers. Off-farm dryers are high-capacity, high-temperature units. Crossflow models are the most prevalent type used in the United States; they dry the grain nonuniformly and cause excessive stress-cracking of the kernels. Mixed-flow dryers are common in other major grain-producing countries; the grain is dried more uniformly in these dryers and is usually of higher quality than that dried in crossflow models. Concurrent-flow dryers produce the highest quality grain; their main disadvantage is the relatively high initial cost. A change from crossflow to mixed-flow or concurrent-flow dryers would benefit U.S. grain quality.

Moisture content and uniformity within a storage facility is critical to maintaining grain quality. The interaction between moisture, temperature, and relative humidity may spur mold growth, increase insect activity, and cause other quality losses (figure 1-1). Basically, grain moisture in equilibrium with 65 percent relative humidity will support mold activity, but different grains will create the equilibrum with relative humidity at different moisture levels. That is why wheat and soybeans cannot be stored at the same moisture content as corn. When controlling insects, high moisture content increases absorption of fumigants such as methyl bromide, requires an increase in dosage, and accelerates the breakdown of pesticides such as malathion.

The equipment and methods used to fill a storage bin affect the performance of aeration systems used to control the effects of moisture/temperature/humidity. Dropping grain into the center of a bin causes a cone to develop, with the lighter, less dense material concentrating in the center (in spoutlines) while the heavier, denser material flows to the sides. This impedes airflow during aeration, and fosters mold growth.

In large horizontal storage areas, loading from the center or from a loader that is gradually moved backward through the center of the building as the pile is formed causes similar problems. If grain is piled over aeration ducts on the floor by moving the loading device back and forth, airflow will be greatly increased. However, airflow distribution is not as uniform as in upright bins. Some methods of filling piles also result in segregation of fine materials. These accumulations are more subject to insect and mold growth, and they divert airflow. But piles are difficult to aerate and the shape of some restricts uniform airflow.

Nonuniform moisture levels can lead to spoilage in localized areas within a storage facility. Moisture and temperature within a grain mass will not remain uniform over time. Moisture will migrate in response to temperature differentials. If the outside air is warmer than the grain, the circulation reverses, and the area of condensation shifts to several feet below the grain surface, although still in the center.

The effect of moisture migration on storage is that grain assumed to be in a storable condition is not. Cold weather migration primarily affects grain in land-based storage, causing deterioration as temperatures rise in the spring. Warm weather migration is particularly vexing for grain in transit from cold to warm areas of the United States and from the United States through warm waters to foreign buyers. A barge or ocean vessel is basically a storage bin and will experience the same migration phenomena as land-based storage facilities.

Broken Grain and Fine Materials.—Some grain damage or breakage generally occurs whenever grain is harvested. Overall, damage is always much greater in extremely wet or extremely dry grain. When grain is harvested at high moisture levels, the kernel is soft and pliable. Moist kernels deform easily when a force is applied and greater force is needed to thresh wet kernels than dry ones. Thus, wet kernels suffer more damage than drier ones. However, drier kernels can break when the same force is applied. Different optimal conditions thus exist for each grain.

In addition to grain breakage, factors such as weed control and kernel density, especially in wheat, also affect a combine's ability to harvest and deliver clean grain. Cutting below the lowest pod or wheat head inadvertently introduces some soil into the combine. Most soil is aspirated from the rear of the combine unless the soil particles are about the same size as the kernel, in which case they pass through the cleaning sieves with the grain.

Harvesting technologies normally separate and remove material larger than the grain (such as plant parts) and material significantly smaller (like sand and dirt). Sloping terrain, however, can affect this process. Side slopes also create problems since the tendency is for material to congregate on the downhill side of the cleaning shoe.

The main factor affecting the combine's cleaning performance is the amount and type of weeds present in the field during harvest. Weed control is one of the most serious problems facing many U.S. wheat producers. This is also true for Southeastern U.S. soybean-producing areas, where a warm, wet climate is conducive to weed growth. The amount of weeds affects not only grain yield, but also the amount of foreign material present in the harvested grain and the combine's ability to remove this material.

Combines are being modified to improve their performance in weedy fields. In the case of wheat, kernel size has been decreasing, which complicates this modification. The trend toward smaller kernel size is a concern because the seeds of most grassy weeds are smaller and lighter than wheat. Thus, smaller wheat kernel size reduces the margin between wheat and weed size and, therefore, increases the difficulty of cleaning within the combine.

Rapidly drying moist grain with heated air causes stress cracking. The drying operation itself does not cause grain breakage, but can make grain more susceptible to breakage during handling later. **Cleaning grain before it reaches the dryer can improve dryer efficiency.** Introducing clean grain to the dryer:

- results in a more uniform airflow in the dryer and thus a more uniform moisture content of the dried grain;
- decreases the static pressure (airflow resistance) of the grain, thus increasing the airflow rate and dryer capacity; and
- eliminates the drying of material that detracts from final grain quality.

Obviously, precleaning also has disadvantages. It requires additional investments in cleaners; the handling of wet, broken grain and fine material; and the rapid sale of wet, easily molding material; and it results in some dry-matter loss. Although the advantages of precleaning wet grain are fairly well understood by dryer operators, most avoid precleaning. The quality of the U.S. grain crop would improve substantially if precleaning were adopted.

Mechanical damage during handling results in grain breakage, which produces broken grain and fine materials. This causes a decrease in quality, greater storage problems, and an increase in the rate at which mold and insects tend to invade stored grain.

Research shows that breakage in handling is more significant for corn than for wheat and soybeans. Higher moisture content and higher temperatures prove to be the best conditions to minimize breakage but are opposite of the optimal safe storage moisture and temperature. The effect of repeated handlings on grain breakage is cumulative and remains constant each time grain is handled or dropped. This is true whether or not the broken material is removed before subsequent handlings.

The impact of grain breakage and fine materials on all aspects of the system has resulted in the need to clean grain. Cleaning wheat in commercial handling facilities is normally limited to removing dockage, insects, and, to a limited degree, shrunken and broken kernels. For corn, cleaning regulates the amount of broken kernels and foreign material; for soybeans, it affects the amount of foreign material and split soybeans.

Cleaning corn to remove broken kernels and foreign material is required at each handling in order to meet contract specifications and avoid discounts. For wheat, however, most dockage is generated during harvest, and normal handling does not cause significant increases. Therefore, cleaning is not required at each handling. Soybeans, on the other hand, fall somewhere in between regarding their breakage susceptibility and the amount of cleaning required at each handling.

The amount of grain cleaning required prior to storage involves the factors of risk to grain deterioration as a result of mold and insect invasions and the costs associated with maintaining quality. Broken grains, grain dust, and other fine materials have the greatest effect on the performance of insect control interventions. When a protective treatment is applied, grain dust may absorb much of the insecticide, which reduces the effectiveness. Likewise when a fumigant is applied, concentrations of dust and fine material may require increased dosages to penetrate the grain mass. Dust also inhibits penetration of fumigant gases causing nonuniform penetration.

Ability of System to Maintain Quality.—Technologies are in place to harvest, maintain, and deliver high-quality grain. Each technology must be used, however, in a manner that is conducive to maintaining quality.

Although the data indicate that nearly any combine can deliver acceptable grain quality, farmer-operated combines tend to record more damage than the combine should deliver. From a technology standpoint two areas need emphasis:

1. increased education to help operators better understand the interactions of cylinder/rotor speed, concave openings, fan speed, and sieve openings with grain quality and losses; and
2. more monitoring devices and possibly automatic controls on combines to help operators adjust or fine-tune the combine.

Weed control and its relationship to kernel size and density are critical to optimum combine performance. Unless new technologies addressing this area are developed or improved weed control measures are forthcoming, the combine's ability to harvest and clean grain will continue to present problems.

A significant improvement in grain quality can be obtained by optimizing the dryer operating conditions of existing crossflow dryers, by precleaning wet grain, by selecting the best grain genotypes, and by installing automatic dryer controllers.

Molds will grow on any kernel or group of kernels that provide the right conditions. Therefore, moisture content and uniformity within storage facilities are critical to maintaining grain quality. **Maintaining low temperatures and moisture levels in grain is the principal way to preserve grain quality and prevent damage from molds and insects.** Aeration is also a very effective tool. The rate of development of both molds and insects is greatly reduced as temperature is lowered.

Many storage bins, especially on the farm, are equipped with aeration systems but often are not used effectively. Farm storage bins, especially smaller and older ones, generally are not aerated. Small bins will cool or warm quickly enough with the changing season that moisture condensation may not be a serious problem. A majority of farm aeration systems are either not operated at all or not used enough. The most common problem is not running the fans long enough to bring the entire grain mass to a uniform temperature level. If a cooling front is moved through only part of the grain, a moisture condensation problem is likely at the surface where the warm and cold grain meet.

In addition to aeration, the turning and transfer process mixes grain and contributes to a more uniform moisture and temperature. In facilities not equipped with aeration, turning has been the traditional means of grain cooling. This approach requires much more energy than aeration does, however, and it can contribute to physical damage by breaking the kernel.

Grain in horizontal or pile storages cannot be turned because of the difficulty in unloading and moving it. In order to turn grain, a handling system must have empty bins that are connected by a conveying system. This is not the case on most farms.

Most grain storage facilities provide a natural habitat for certain harmful insects even when the facility is empty. Grain residue trapped in floor cracks and crevices, in wall and ceiling voids, and on ledges provides an ample supply of food to sustain several insect species. Thorough cleaning is the first and most effective step toward preventing insect infestation of freshly harvested grain. Because insects live from season to season, cleaning and removing trash and litter is important. Also, a thorough cleaning should precede any insecticidal treatment of storage facilities if the full value of the treatment is to be gained.

For several reasons, such as remoteness of facilities, small amounts of grain to be treated, and lack of information, farm storage facilities are often the inappropriate site for insect control treatment. Grain that has not received a properly applied treatment can become mixed with noninfested grain when marketed, magnifying the problem and creating greater loss and the need for more expensive and time-consuming remedies later.

The high-speed, low-cost U.S. grain system does not readily accommodate special quality needs. While these needs can be met by slowing belt speed, installing and using cleaning equipment, eliminating unneeded handlings, and preserving the identity of grain, most of these actions increase costs.

All factors affecting quality just discussed—nonuniform moisture, moisture migration, temperature and humidity, insect invasion, and mold development—have an impact on grain quality during shipment. No mode of transportation is equipped with aeration, nor can grain temperatures and corrective actions be taken during shipment. Moisture migration can be more dramatic since grain may undergo several outside air temperature and humidity changes. This is especially true when grain is loaded in a cold climate and transported through warm waters rather quickly to a warm, humid climate. Therefore, moisture uniformity is critical to maintaining quality during shipments.

The interactions between technologies regarding moisture content and breakage on grain quality are evident. Each technology is capable of preserving grain quality. Once inert material such as weed seeds, dirt, stems, cobs, and so on are removed from the grain, no further cleaning is required. But grain, especially corn, must be cleaned to overcome breakage that is inevitable due to handling in the system. Once grain quality deteriorates at any step in the process, it cannot be recovered.

Grain Standards

Standards should reward positive actions, such as genetic improvement and sound harvesting, drying, and marketing practices. They should also incorporate descriptive terminology that provides the best information available on the value of each shipment. **All changes must be evaluated against the criterion of providing information that is worth the cost of obtaining it.** Optimum information, not maximum information, is the goal. Proposals for change must be tempered by current capabilities of the industry, the cost of adjustments versus potential benefits, the realities of international trading rules, and history of the grain industry. Measurement and description of quality is only one part of the problem. Quality must be evaluated in the context of technology, competition, foreign demand, and processing requirements.

Current grain standards are limited in four important ways:

1. They create incentives for practices inconsistent with good management and efficiency.
2. They fail to identify many of the characteristics related to value in use.
3. They fail to reward producers and handlers for improved drying, harvesting, handling, and variety selection.
4. Grade limitations on many factors are arbitrary, sometimes not reflecting real differences in value, and in some cases are not consistent with statistical principles.

No ideal standard will be found, and any revisions would have to consider trade-offs. To move toward an ideal system, grain standards should be changed to include:

- grade-determining factors;
- non-grade-determining factors; and
- definition and measurement technology for official criteria.

Grade-determining factors should relate to sanitary quality, purity, and soundness (absence of imperfections). Grade would be based on factors such as impurities, foreign material, total damage, and heat damage. The lower the values of any of those defects, the greater the value of the product.

Non-grade-determining factors would address properties such as broken kernels, moisture, oil and protein content, and other intrinsic characteristics or physical properties that influence values for major processing uses. Higher or lower percentages for those do not necessarily mean higher end-use value. Many chemical and physical properties that influence the quantity and quality of products derived from grain probably are yet to be identified. More research may add to the list of properties. The criteria for inclusion should be that the cost of obtaining the information is less than the value of that information to users who need it. By starting with the major products generated from each grain, a list of physical and chemical properties can be developed that are correlated with the value in use. New rapid testing technology is also a requirement prior to inclusion.

Official criteria factors would be those requested by buyers and sellers. These would be developed only after evidence of sufficient demand to cover the cost.

Grain can be inspected many times as it moves from the farm to its ultimate destination. Normally it is tested for one or more important characteristics each time it is loaded into and out of a grain elevator. The number and type of tests varies, from those provided for in the grain standards to measures of intrinsic characteristics not covered by the regulations.

The U.S. Grain Standards Act (USGSA) requires that standards be developed and used when marketing grain. **Even though the tests provided for in the grain standards must be used, no requirement exists on who will perform the tests and what tests will be performed on grain moving domestically in the United States.** In fact, two U.S. Department of Agriculture agencies are authorized to perform testing services using the grain standards on domestic grain movements. The only mandatory testing is performed by the Federal Grain Inspection Service (FGIS) on export grain.

Since no single policy on inspecting grain exists, no one group is responsible for developing and overseeing the tests and equipment being used. Regardless of which tests are performed and who performs them, several factors are important to testing. These include instrument precision, instrument standardization, the choice of reference methods and traceablility to standard reference methods when developing rapid objective tests, calibration, and natural error resulting from sampling.

As the relevance of additional tests performed on an ongoing basis becomes clearer, the need for standardizing equipment and procedures becomes more critical. Also, criteria must be established to govern the design of rapid test equipment. However, development of rapid tests must meet the basic criteria associated with standardization, traceability to standard reference methods, and calibration. In addition, rapid tests must be evaluated in terms of speed, cost, accuracy, durability, and capability of handling wide ranges in quality.

Buyers' Attitudes

An extensive survey of domestic and overseas grain buyers was conducted for this study to determine their attitudes toward quality, grain standards, and merchandising practices. Several general points of importance were clear.

First, to determine what is considered quality for any given grain, the ultimate use must first be known. Each domestic and overseas industry has defined quality in terms of the areas important to its markets.

Regarding key attributes not currently covered by grain standards, no one set of quality attributes for wheat meets the demands for all wheat products. Differences in what are considered important attributes exist between domestic and overseas wheat millers and by region of the world. Protein, hidden/dead insects, falling number, pesticide residue, mycotoxins, and dough handling tests were considered the most important. Falling number and pesticide residue were identified by both groups as tests that should be included in the wheat standard. Hidden or dead insects were also identified by domestic millers for inclusion.

For corn, the determination of important attributes is industry-dependent except in areas regarding wholesomeness, health, and safety. Items such as stress cracking, breakage susceptibility, and hardness are more important to wet and dry millers than to the feed industry. However, attributes such as pesticide residue, mold, mycotoxin, and hidden/dead insects are important to all those surveyed.

Commonality of important attributes is more evident in soybeans than in wheat or corn between domestic and overseas processors. The most important attributes are protein, oil, and free fatty acid content.

Second, the grain system's ability to deliver important quality attributes consistently is as important as the attributes themselves. Problems with uniformity are especially acute in wheat and corn. As processing technologies become more sophisticated, the demand for uniformity will become more critical.

U.S. Farm Policy

Two important features of U.S. farm policies have an impact on several aspects of quality. **The inverse relationship between yield and intrinsic quality (e.g., protein in wheat) means the target price program) has a negative long-term impact on intrinsic quality.** This is because the target price typically exceeds the market price, creating an incentive to expand yields. Impacts vary by grain and region, depending on the extent of the inverse relationship. When target prices, which are based on yield, exceed market prices and if the premiums associated with the measure of intrinsic quality are unchanged, there are incentives to increase yield at the expense of intrinsic quality. This effect has been exacerbated in previous farm bills, which used different methods of determining yield. The total impact in the case of wheat has been to force market premiums for wheat protein to relatively high levels in order to neutralize producers' decisions.

Administration of the loan rate program also has an impact on intrinsic quality, as well as on physical and sanitary quality. **In particular, the market for measurable quality characteristics is distorted due to the fact that premiums and discounts on forfeited grains, especially wheat, are less than those determined in the market.** Poorer quality grain is put under storage, and market differentials are depressed.

Changing Role of Demand

Wheat, by its very nature, is the most complex of the three grains for defining quality because of the vast array of products and processing technologies used to produce the products. Corn is somewhat less complex in that fewer products are produced and quality concerns can be traced to the individual industries. On the other hand, the quality required by one corn industry is not necessarily important to others. This creates a situation whereby decisions regarding corn quality must be assessed in terms of major usage. Quality concerns of different industries using wheat are somewhat overcome by the fact that different types of wheat exhibit different properties. Soybean quality is the least complex issue because the vast majority of soybeans are used to produce oil and meal.

The varying quality requirements exhibited by these industries highlight the need for the United States to become more aware of individual industry requirements if the goal is to produce and deliver high-quality grain. The United States has developed the reputation as a consistent supplier for any type and quality of grain desired. **To become a supplier of high-quality grains, it must become more quality-conscious and develop a reputation as a high-quality supplier.** The Nation must understand the specific quality requirements of its customers in order to match them with the quality delivered, and must become more aware of the dynamic issues surrounding the qualities required by the marketplace. Areas such as technological advancements in processing technologies, government policies, customer preference, development of new finished products, and consumption patterns all affect customers' purchasing decisions and their definition of quality at any one point in time.

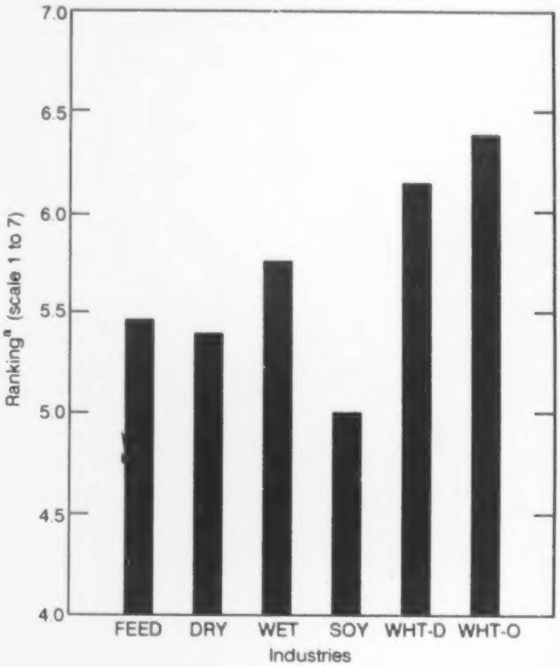
Quality in the Marketplace

Quality attributes required by individual industries directly relate to the processing technology used and the needs of the various finished products. In the case of corn, what may be considered high quality to feed manufacturers is not necessarily high quality for the wet and dry milling industries. Wheat, used in a multitude of products, has quality requirements that differ not only by type and individual product, but between mills using the same type of wheat to produce flour for the same type of product. Baking technologies for wheat flour vary not only in the United States, but also within and between countries using wheat purchased from the United States; so defining one set of wheat quality characteristics for even one type of wheat or flour is not useful.

High quality, as defined by the specific attributes required by each industry, is constantly changing. However, the ability to produce and deliver high-quality grain can mean more than just providing grain that meets specific test results. What constitutes high quality from the customer's point of view can range from special handling (low-temperature drying of corn) to the uniformity of specific attributes within and between shipments.

The OTA survey specifically asked respondents to rank the importance of uniform quality between shipments (figure 1-2). **Domestic and overseas respondents considered uniformity between shipments as being important even though they differed on which attributes were more critical.** The results from the question regarding overseas millers' preference for U.S. wheat compared to that of other exporters further demonstrates the importance of uniformity. **Canada and Australia stress uniformity between shipments and this fact generally accounts for wheats from these countries being ranked as first choice.**

Figure 1-2.—Importance of Uniformity Between Shipments



ABBREVIATIONS:

FEED = Feed manufacturers
DRY = Dry millers
WET = Wet millers
SOY = Soybean processors
WHT-D = Wheat millers (domestic)
WHT-O = Wheat millers (overseas)

[a] 4.0 Neutral
5.0 Slightly important
6.0 Moderately important
7.0 Extremely important

SOURCE: Office of Technology Assessment, 1989

To further complicate the task of identifying important quality attributes for specific industries, some traditional measuring technologies are not accepted by certain industries producing the same product. This fact stood out in OTA survey results for domestic and overseas wheat millers. Tests for rheological properties (extensograph, alveograph, and mixograph) were considered more important by overseas wheat millers than by domestic millers. And even though overseas millers considered these tests important, their importance varies by region of the world.

As processing technologies become more sophisticated through automation or as more demanding qualities are required for finished products, the need for specific attributes within well-defined ranges becomes more critical. Technologies for baking bread, rolls, and similar products in large bakeries have advanced significantly. While bread can be made by hand using low-protein wheat, large dough-mixers and other equipment found in large automated bakeries place too much stress on low-protein flour, resulting in unacceptable finished products. The differences in how flour will be baked plays a very important role in determining the specific values for the various attributes required of the flour.

In addition to advances in processing technologies, technological advances in other areas can have an impact on the quality required by different industries. For many years, high-protein wheats have been blended with low-protein wheats to strengthen flour. More recently, vital wheat gluten, a product containing 75 to 80 percent protein, has been used as a flour fortifier. The recent expansion of vital wheat gluten production is the result of technological improvements in breadmaking, rapid population growth, and increasing trend toward urbanization in some countries.

Many countries striving to become self-sufficient in wheat production are producing vital wheat gluten to fortify locally produced low-protein wheat. Some European processors are also producing isoglucose, a sweetener and sugar substitute, from wheat starch (that portion of the wheat kernel remaining after the gluten is extracted) to produce something similar to corn sweetener in the United States.

Corn, which has always been considered mainly as an animal feed, is beginning to experience pressures in areas similar to those affecting wheat. As feed manufacturing becomes more sophisticated and automated, and as customers (especially in the poultry industry) need strictly controlled and balanced diets, the demand for quality attributes and consistency in delivering these attributes is taking on increased importance. In other cases, individual corn dry and wet milling companies are placing more stringent demands on the quality of corn they purchase. Companies are contracting with farmers to grow certain varieties and perform special handling, such as low-temperature drying.

Traditional quality attributes, even though varied, may be influenced by technological advances, economic concerns, and government policies here and abroad. **For the United States to produce and deliver high-quality grain, it must not only become increasingly aware of concerns over quality expressed by domestic and overseas industries and match quality to their wishes, but it must understand the reasons why countries purchase grain in the first place.** Knowledge of customer preference, consumption patterns, and the role of government policies is critical when considering steps the United States should take to enhance the quality of grain in international trade.

POLICY OPTIONS

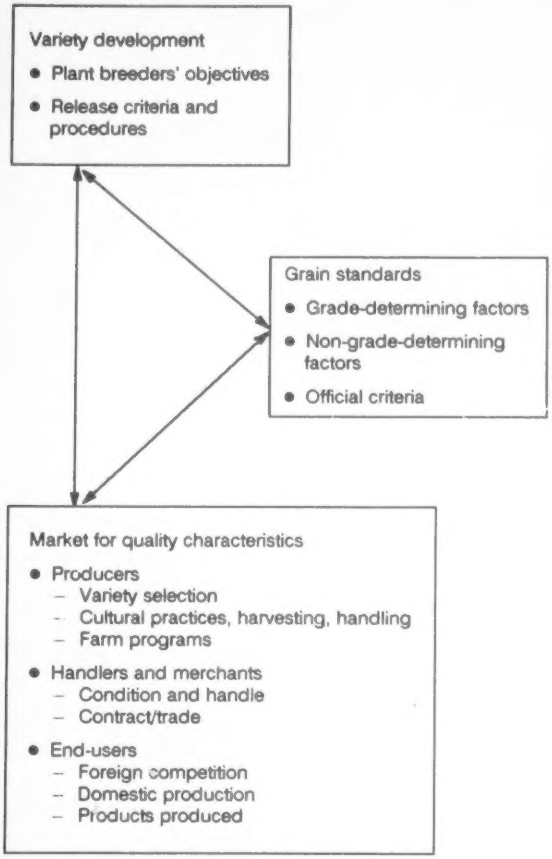
The overall purpose of any policy change related to this grain issue must be to create an environment that enhances grain quality. In general, the important features of the U.S. grain system are breeding, handling, grain standards, and the market for quality characteristics. Each has an effect on grain quality. Institutions, policies, and trade practices have an impact on these sectors, and therefore on quality. **Policy discussion in this country has traditionally focused on only one component of the system—grain standards.** Yet given that it is the operation of the overall system that influences grain quality, a far greater number of policy options exist than are normally discussed.

The notion of interdependence in the production and marketing system with respect to quality is illustrated in figure 1-3. This triad could be viewed as a three-legged stool; each leg has an impact on quality as well as on the system.

Premiums and discounts for quality characteristics are determined in the market, where buyers and sellers interact. Producers make varietal and agronomic decisions in response to incentives. These, however, are also influenced by farm programs. The demand for characteristics is influenced by end-use needs and foreign competition. Merchants and handlers procure, handle, condition, and blend grain to meet contract specifications. In addition, they make offers on what they can sell, and at what price differentials, based on the availability of quality characteristics and their conditioning capabilities. Each activity is influenced by the incentives established in the market, by trading rules, and by grain standards, which provide a description that is useful for transactions and which therefore facilitate trade. Relevant end-use characteristics generally are not included in grain standards, however.

The objectives of public and private plant breeders in variety development include yield, disease resistance, harvestability, and quality. In addition, participants have procedures and

Figure 1-3.—Components of the Interdependent Grain System


Variety development
• Plant breeders' objectives
• Release criteria and procedures
Grain standards
• Grade-determining factors
• Non-grade-determining factors
• Official criteria
Market for quality characteristics
• Producers
– Variety selection
– Cultural practices, harvesting, handling
– Farm programs
• Handlers and merchants
– Condition and handle
– Contract/trade
• End-users
– Foreign competition
– Domestic production
– Products produced

SOURCE: Office of Technology Assessment, 1989

criteria for variety release. Ultimately, the market for seed determines the success of varieties. Some characteristics, e.g., yield, are more easily measured than others by market participants. Breeders also have some control over intrinsic quality characteristics that are not easily measured in today's marketing system.

The interdependence of the system's components must be recognized in the evaluation of policy options with the objective of establishing a more integrated relationship among them. In a number of other grain exporting countries, the policies are more integrated and better coordinated. In fact, the United States has made no effort to coordinate or integrate policies affecting these activities. Any policy on grain standards will affect varietal development and the efficiency of the market for quality characteristics. Similarly, any policy affecting the market (e.g., incentives) will have an impact on variety development and grain standards. The inability to measure intrinsic characteristics in grain standards has implications for policies affecting the market and variety development.

Policy changes could be focused on any system component, but the effectiveness must include impacts elsewhere. A number of phenomena that influence quality (e.g., weather) cannot be affected by policy and a number of policies are short-run and only treat symptoms. **Policies developed here aim to affect underlying causes of the problem, which over the long term would result in improved quality. Thus the policy options are limited to three general categories—variety controls, market intervention, and grain standards (table 1-2).** Within each are a multitude of alternatives, and only selected ones are presented. Policies available are a continuum within each category rather than discrete choices, as implied by the table. **The emphasis here is that policy should take the long view, and it should have the objective of coordinating policies across the three sectors.**

Variety Controls

Three important considerations lead to the policy options listed under variety controls. First, with few exceptions grain standards do not measure important intrinsic characteristics. Second, intrinsic quality characteristics differ significantly across some grain varieties. Third, varieties are not visually distinguishable, thus segregation in the market system is precluded, resulting in increased uncertainty in end-use quality. These three points apply to some extent to each of the grains. The classic case is that of wheat, in which performance varies across varieties, and increasingly it is becoming difficult to differentiate wheat in the marketing system. In some of these cases it may be easier to identify variety, or groups of varieties, than intrinsic characteristics. Further,

Table 1-2.—Fundamental Policy Alternatives

Variety controls	Market intervention	Grain standards
No change	Marketing board	Mandatory USGSA inspection
Variety identification/ categorization	Export bonus	Single agency to approve testing
Variety licensing	No change in loan policy	Mandatory USGSA inspection in conjunction with NIST equipment approval
	Increased differentials in government policies	
	Minimum quality specifications for farmer loans	

SOURCE: Office of Technology Assessment, 1989

identity of a variety provides more comprehensive quality information than any subset of measured quality characteristics.

Domestic processors attempt to resolve problems of varietal differences, to some extent, by purchasing by location or region. Foreign buyers, however, or in general any buyers using purely grade specifications are precluded from this alternative.

No Change

Maintaining the status quo has four main implications. ***First*, intrinsic quality characteristics will continue to lack uniformity among States/regions/shipments.** In the current system, with only informal, uncoordinated variety release criteria, many basic characteristics differ among varieties. These characteristics lose their identity in a market incapable of measuring end-use characteristics. Consequently, important intrinsic quality differences existing regionally are not detected in the marketing system.

***Second*, problems will be created elsewhere in the system due to the inability to measure intrinsic quality.** In particular, increased pressure would be placed on grain standards to measure intrinsic quality within the marketing system.

***Third*, the current lack of information on intrinsic quality in some grains will continue, reinforcing current inefficiencies in the market.**

***Fourth*, productivity growth would be facilitated to a greater extent given complete freedom on variety release and selection.**

If there is no change from the current system of administering variety release, the pressure on grain standards to introduce measures of intrinsic quality will increase. Other countries use variety identification and release procedures in part to reduce the pressure on grain standards to measure intrinsic quality. Alternatively, by incorporating intrinsic quality into farm program policies (discussed later), at least some incentive could be built into the system to improve intrinsic quality.

Variety Identification Categorization

Any sort of variety identification or control scheme would pose administrative challenges. **One alternative would be to provide a mechanism in which varieties can be identified in the market system. Such mechanisms currently exist and are used in other exporting countries. These consist of an affidavit system, random testing using electrophoresis, and categorization.** Producers would declare the variety at the point of first sale or loan application. This would provide information to handlers on segregation based on grain categories or groups of varieties. Categories would be developed according to end-use similarity and could become part of the grain standards.

Alternatively, variety or groups of varieties could become part of the contract governing the transaction, as is the case in the French system. The number of categories established would vary by grain, depending on the three considerations just discussed and on end-use specificity. Thus, for example, if only one end use existed and the varieties did not differ sufficiently with respect to intrinsic quality, only one category would be necessary. On the other hand, for wheat, in which there are intrinsic differences across varieties and a multitude of end uses, there would be a larger number of categories. The intent here would be to formalize a mechanism not dissimilar from the current system of classification for wheat. The difference, however, is that the current system for classification relies on visual distinguishability, and categorization is based on fairly imprecise criteria.

A variety control scheme would increase information (by category of varieties), thus increasing the efficiency of the market in its allocative role. For most grains, variety is a better indicator of quality than are selected tests for quality. Thus, buyers' information regarding quality would be improved. The increase in information would raise the efficiency of the market, resulting in improved signals being transmitted to producers, breeders, and end-users.

Such a program would pose a challenge for administration in the United States, especially given the numerous varieties currently grown. It would be further complicated by the fact that intrinsic quality depends not only on variety but also on where it is grown and on local climatic factors.

Contract specifications would increase in complexity. The informational requirements for contract specification would increase, particularly of foreign buyers. Depending on the extent of categorization, however, this complexity could be reduced.

Introduction of a variety identification scheme would result in incentives and disincentives being readily associated with varieties with desired/undesired intrinsic characteristics. In addition, using a variety identification scheme would reduce pressure on the grain standards to measure intrinsic performance in the marketing system. Categorization of varieties would serve that function.

Variety Licensing

A more restrictive approach would be to institute a variety licensing scheme. Varieties would be subjected to criteria administered at a national level for release into the market system. Licensing of varieties takes various forms in different exporting countries—from quite restrictive, such as in Canada and Australia, to fairly neutral, as in France. The intent of each, however, is to provide some mechanism that assures certain intrinsic characteristics, given that they cannot be easily detected in the market system, and to apply uniform criteria throughout the country, i.e., to reduce uncertainty of intrinsic characteristics through uniform application of release criteria. Administration would require procedures similar to those of the variety identification system just described. In addition, some criteria would have to be established for categorization (i.e., to license varieties by end use), and for administration.

Licensing varieties would increase uniformity and raise the ability to control intrinsic quality. A formal mechanism could be provided for categorization relative to a simple variety identification scheme. Due to locational differences in quality, varieties would have to be licensed by location and by end use.

Depending on administration, this scheme could be viewed as restrictive, i.e., of productivity growth. However, this is not necessarily the case, as the situation in France indicates. This approach would be difficult to implement, complex to enforce, and likely to create a bureaucracy.

A stricter variety licensing system would have similar effects on other parts of the system as just discussed under variety identification. In particular, licenses could act as surrogate grain standards for intrinsic characteristics.

Market Intervention

Marketing Board

Central to the U.S. system is the market in which prices are established. Embedded in this market, and all prices, are premiums and discounts for measurable characteristics, which allocate grain across different users. In addition, these quality characteristics provide incentives and disincentives for participants throughout the marketing system. Several other countries accomplish this by some form of board control. **Thus, one option would be to introduce a marketing board system in the United States to resolve quality problems.** The emphasis of the discussion here is on the implications of a board for quality, in particular, and the coordination of policies on quality. Other aspects of a board operation are more far-reaching (e.g., bargaining power, resource allocation, impacts on non-board grains, impacts on physical coordination) and are not discussed here.

A primary benefit of a marketing board would be to coordinate the many aspects of the production and marketing system that have an impact on quality. Quality would be improved to the extent that only two transactions—one between producer and board, and another between board and buyer—would take place. This is in contrast to the multitude of current transactions, all requiring measurement of quality.

Administration of price differentials would be more subjective and judgmental in such a system since transactions would take place without an active market. Indeed, market determination of price differentials is an important advantage and role of the U.S. marketing system.

Operating a grain marketing board in the United States would be costly, given the complexity and breadth of the system. Countries with boards operate in relatively simple logistical systems, and with few grains. When either of these increases, as would be the case in the United States, the problems associated with bureaucratic allocation decisions intensifies. The highly efficient U.S. grain handling and distribution system, due in part to the competitive environment, would be lost in a board-type system. Thus, it is likely the costs of imposing a board system in the United States would outweigh the benefits of quality improvements.

Imposition of a board system could reduce the emphasis on grain standards at the point of export, and for that matter throughout the system. This is presuming that sufficient earlier controls were imposed to resolve grain quality problems, thereby reducing the importance of quality measurement at the point of export. In addition, variety release procedures could be easily administered in a board system. Incentives could be administered rather than having to rely on market determination.

Export Bonus

An alternative policy would be to establish a bonus payable to exporters who deliver grain having quality superior to that specified in the contract. Conceptually, this addresses the system's merchant-handler component. This policy is discussed in the context of being applied at the point of export, but in general it could be applied elsewhere in the marketing system.

An export bonus program could have immediate results, especially if tied to a physical or sanitary quality characteristic. It would result in an increase in quality perception, or in attention to the issue. Longevity should be a concern, however, in that if terminated, the effects likely would not last.

Administration would be costly. Several important administrative points would need to be considered. First, which quality characteristic(s) would be tied to the bonus--physical, sanitary, or intrinsic? Quality would improve on whatever characteristic received a bonus. Depending on longevity, however, the bonus would likely not influence intrinsic quality. Second, should the bonus be applied at the point of export or origin? One risk is that importers may manipulate the system by specifying a lower grade in order to receive the same grade they traditionally purchase, but at a lower price.

An export bonus program, by definition, would be oriented to the merchants and handlers in the system. It would provide incentives for them to improve the quality on particular attributes and for particular shipments to which the bonus was applied. Due to competition within the industry, any benefits would be distributed to appropriate decisionmakers so as to provide incentives. **More information would not be provided to the market, however, nor would there be a reduction in information uncertainty, so the efficiency of the market would**

not be improved. Breeders' objectives and release criteria would be affected only to the extent that the bonuses were applied to intrinsic characteristics, and over very extended time periods.

No Change in Loan Policy

Another option is to leave unchanged the current administration of the policy on loan forfeitures and grain stored for the Commodity Credit Corporation (CCC). The fundamental problem is that price differentials for loan forfeitures and transactions on CCC-owned grain are substantially less than those in the market. The market for quality characteristics is therefore distorted. **The loan and CCC storage practices would continue to support the price of lower quality grains.** In addition, there would be essentially no change in intrinsic, physical, or sanitary quality from that of the current system.

Lower quality grain under extended storage could deteriorate more than if it were of superior (physical and sanitary) quality. Growers would remain isolated from the market and therefore incentives for improving quality would be masked.

The market is distorted in general in the allocation between storage and commercial sales, with superior quality grain going to the latter. Since the program does not effectively distinguish intrinsic quality, loan rate disincentives are not effective at transmitting signals to producers. **Thus, a major impact of not changing the policy would be to increase the role and function of grain standards in measuring quality.**

Increased Differentials in Government Policies

The administration of premiums and discounts for loan forfeitures and transactions involving CCC-owned grain could be revised to provide incentives to maintain or enhance quality. These could be attached to intrinsic as well as other physical and sanitary quality characteristics. In a number of other countries, quality problems are addressed as a matter of agricultural policy. These take the form of incentives by using regulations and substantial premiums and discounts for quality deviations. Realigning the incentive system via farm policy addresses one component of the system, i.e., the market for quality characteristics. That market already exists and develops premiums and discounts. But it is distorted somewhat by administration of the farm program. This policy option would thus be eliminating a distortion, which would allow the market to function more efficiently. Alternatively, farm policy could take the lead by providing price differentials at least equal to market differentials, to provide incentives throughout the system.

CCC administers programs for handling and storing CCC-owned grain. **Different rules are applied to country and terminal elevators.** CCC requires that terminal elevators deliver the quality represented by the warehouse receipts and it discounts individual railcars. CCC does not pay terminal elevators for overdeliveries in quality. This is not the case for country elevators, which are not subject to the same rejection rules if the quality delivered is inferior to the warehouse receipts and which receive payment for overdeliveries.

One of the few ways to legislate incentives into the system, particularly for intrinsic quality, is via the price differentials in the loan program. This alternative consists of differentials associated with loans to be greater than or, alternatively, equal to the market. They could be applied as currently done, on grades, or on specific physical and sanitary quality criteria. A very simple example would be a 4-cents/bushel price differential for clean wheat (i.e., less than 0.5 percent dockage). In addition, measures of intrinsic quality (e.g., falling number in wheat, oil content in soybeans, or protein content in corn) could be incorporated, as in other countries.

Because the relationship between market prices and loan values varies across grains, and because the participation rates vary, this policy would have a greater impact on wheat than on other grains. In addition, its impact would only be periodic due to the loan not being effective all the time.

If the loan supported prices of higher quality grain, lower value grain would be forced into the market, as opposed to into the loan program, as currently happens. Thus, there would be an increase in the amount of grain going into alternative uses, with lower end value. The most vivid example is the use of wheat as animal feed. Incentives for intrinsic quality could be relatively easily incorporated into the loan program (i.e., relative to measuring them in the marketing system).

Some type of mechanism for quality measurement would have to be developed for grain going under loan, e.g., through farmers submitting samples. Establishment of the optimum price differentials would be difficult to administer. This is especially true given the large number of U.S. markets and given that—at least in the past—loans have to be announced long before crop quality is determined.

Country elevators would be forced to become more concerned with maintaining quality, and CCC would be guaranteed that the quality of grain received into the country elevator would be delivered out of the elevator. This change in policy would also relieve the pressure of maintaining discount schedules that reflect the market, in that CCC would not accept quality below that specified in the warehouse receipts.

This particular alternative addresses the market for quality characteristics, and provides incentives in an important market for some grains. **Changing the current system would have a number of system benefits. First, to the extent that intrinsic characteristics are used, variety development would be favorably affected.** Signals from this important market would be transmitted directly to breeders and would affect their breeding objectives and release criteria. Thus, this provides somewhat of a surrogate for variety control. **Second, there would be somewhat reduced pressure to measure intrinsic quality in grain standards.** In the extreme of a proactive farm policy, together with variety identification/licensing, the role and function of grain standards could be reduced to some extent toward measuring physical and sanitary quality characteristics.

Minimum Quality Specifications for Loans

An alternative used in many countries is that of minimal receival standards on grain entering the marketing system. Normally grain marketing is integrally related to prices and policies (e.g., initial payments) and therefore it is difficult to isolate physical marketing from pricing. **As developed here, minimum quality specifications would be applied to grain entering the loan program as opposed to grain entering the marketing system.** The global application of minimum quality specifications to the U.S. marketing system would be next to impossible to implement since a majority of grain under loan is stored on farms.

The concept of setting minimum quality specifications for loans is similar to the option just discussed, except that a constraint, rather than a price incentive, is used for entry into the loan. Minimum quality specifications could be applied to physical characteristics (e.g., minimal dockage) or intrinsic characteristics (e.g., variety, protein, falling number, oil, or meal protein). If these were integrated into the loan program, the potential exists for grain not meeting those specifications to be diverted to the export market. One way to help minimize this would be to use whatever quality specification has been established for government programs as a basis for rejecting grain going into an export elevator. This would have the added benefit of reducing the spread of qualities available for blending within the export elevator.

This policy option would have many of the same advantages as increased differentials in government policies. But the minimums would be difficult to establish and maintain in today's political environment. The desirable quality characteristics to be incorporated in the loan program could also be those not easily measured in the marketing system. Depending on the minimum quality specifications (physical, sanitary, intrinsic, or variety), farmers could be required to certify the variety planted or to submit samples of the grain being stored for testing as directed by the U.S. Department of Agriculture.

Use of minimum quality specifications could also solve, or contribute to, the resolution of problems elsewhere in the system. Desirable varieties or intrinsic characteristics, if used, would transmit signals to breeders. These would influence their objectives and release criteria. In addition, the role and function of grain standards in the marketing system as they pertain to measuring intrinsic quality could be reduced to some extent.

Grain Standards

The U.S. Grain Standards Act states that it is Congress' intent to promote the marketing of high-quality grain to both domestic and foreign buyers, and that the primary objective for grain standards is to certify grain quality as accurately as practicable.

Mandatory USGSA Inspection

The Federal Grain Inspection Service establishes grain standards, which includes developing technology to measure the factors contained in the standard. The agency also develops and publishes sampling and inspection procedures, evaluates and approves inspection equipment for use during inspection, monitors the inspection accuracy of its employees and licensed inspectors, and periodically tests sampling and inspection equipment for accuracy. Mandatory export inspection is required and a system of delegated and designated agencies, along with FGIS oversight, is in place to perform domestic inspections upon request. **Therefore, a basic structure is in place for approving and overseeing all equipment and procedures used for measuring grain quality characteristics.**

Having mandatory inspection on interstate grain shipments would ensure that the factors covered by the standards are tested using approved equipment and procedures. It would provide consistency in test results in that the identical procedures are used for each inspection in the marketplace and are performed by independent, government-sponsored agencies.

Mandatory inspection would focus the primary responsibility for grain quality measurement on one government agency. The basic framework is in place through the delegated and designated agencies, which already own approved equipment and have trained employees who use FGIS-published procedures. Even though these agencies are in place, their ability to cover the wide areas required to meet the needs of country elevators receiving trucks is severely limited. This fact, coupled with past problems of regulating truck movement, makes this policy option only applicable to railcar and barge shipments.

Imposing this requirement on the market will increase costs associated with obtaining inspection of grain that would not normally have to be inspected (i.e., grain moving from one facility to another owned by the same company).

Approval of Testing by a Single Agency

The National Institute of Standards and Technology* (NIST), through the National Conference of Weights and Measures, standardizes weights and measures by developing specifications for instrument precision and accuracy along with scale tolerances. Currently, NIST addresses neither grain measures other than weights nor sampling equipment. In some instances, individual States have developed criteria for approving inspection equipment and monitored equipment accuracy. (Moisture meters and mechanical truck probes are prime examples.)

NIST, in consultation with FGIS, could take the lead in developing and maintaining equipment specifications and maintenance tolerances. These actions could be in conjunction with developing new tests that would be included in the standards by FGIS. All equipment used to measure grain quality attributes would then be standardized and traceable to national standards. Variations in testing results introduced by a wide range of equipment accuracies would be minimized. **Only approved equip-**

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*The National Bureau of Standards was recently renamed the National Institute of Standards and Technology (NIST) with the passage of the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418) as of August 1988.

ment could be used to provide testing results, and NIST oversight would ensure accurate testing.

The basic framework is in place for this policy option in that NIST already has established approval procedures, publishes user requirements, and enforces its provisions through State organizations. **Having NIST be ultimately responsible for approving grain testing equipment that serves as the basis for the grain standards has the advantage of placing responsibility in an agency that does not have a vested interest in the equipment's use.** Yet, NIST does not cover tests that are subjective in nature, such as odor, wheat classing, and the determination of damaged kernels. Nor does the bureau have any experience in basing a national standardization program on reference methods that are defined rather than proven.

Other than equipment approved by FGIS or individual States, no other equipment is approved. **Converting to approved equipment would result in increased costs for those having to dispose of unapproved equipment and purchase other equipment. This policy option does not address who will use the equipment and when it will be used.**

Mandatory USGSA Inspection in Conjunction With NIST Equipment Approval

A policy that requires mandatory USGSA inspection on grain moving in interstate commerce and a broadening of NIST involvement into grain sampling and testing equipment captures the advantages of both these options while minimizing many of the disadvantages of either.

The advantages of mandatory inspection on railcars and barges moving in interstate commerce ensures that consistent sampling and testing are performed on both subjective as well as objective factors and that one agency is responsible for grain testing as well as standards development. The inability to perform USGSA testing on trucks and at country elevators can be offset to some extent by involving NIST and its related support systems in the grain testing area. Even though USGSA inspection would not be performed, those groups that do perform testing would be required to use approved equipment and to follow user requirements spelled out in the NIST approval. This would be the same equipment and user requirements that USGSA inspectors use.

This policy option would allow country elevators to continue to perform their own testing services on grain received from the farmer, thus reducing the potential increase in costs associated with mandatory USGSA inspection. However, it would create more uniform testing since anyone performing grain quality testing will be required to use NIST-approved equipment and to follow published user requirements. Coupled with the NIST State support systems already in place to oversee equipment accuracy and ensure that user requirements are followed, NIST involvement would provide oversight in previously uncovered areas.

Interaction Between Standards, Variety Control, and Market Intervention

The interdependence between variety control, market intervention, and grain standards is complex. The debate over grain quality has focused primarily on grain standards, but physical, sanitary, and intrinsic grain qualities are a function of the variety planted, farmer practices, environment and geographic location, handling practices, end-user preferences, marketing, government policies, and the system's ability to measure these factors accurately. Therefore, policy options have an impact on many areas, not just on grain standards.

Policy alternatives outlined in the variety control section address intrinsic quality characteristics, since physical and sanitary quality cannot be addressed through such programs. Policy choices discussed in the market intervention section can address the easily measurable factors for physical and sanitary quality, and can be expanded to deal with intrinsic quality attributes once technology is developed to measure them in the marketplace.

In both the variety control and market intervention sections, an option for no change in present policies has been provided. Such an approach places the responsibility for physical, sanitary, and intrinsic quality solely on grain standards. For the physical and many sanitary quality concerns, relying on the grain standards is a relatively simple matter that does not involve adoption of new technology. It involves taking existing factors and applying appropriate criteria. Several factors could be combined (as is the case of foreign material and dockage in wheat, as many have suggested, as either grade-determining or non-grade-determining) or factors could be separated (as is the case with broken kernels and foreign material in corn) to describe quality more accurately. In addition to rearranging existing factors into grade-determining, non-grade-determining, or official criteria, fixed percentages could be established for certain factors that transcend all grades (e.g., maximum level of dockage in wheat or maximum moisture levels in corn and soybeans). Limits for current factors (e.g., stones or live insects) could also be tightened.

Making no change to variety control systems or market intervention has a dramatic impact on grain standards, however, in that they must be able to address the buyer's desire for information on important intrinsic characteristics and take the lead in establishing signals regarding quality for the entire system. At the moment, technology to measure intrinsic attributes easily in the marketplace is not available. **If standards are to be the vehicle for providing information on intrinsic and many new sanitary quality characteristics (e.g., pesticide residue), resources must be provided to develop the technologies needed to measure them accurately and easily before the market can respond.** It will take many years to research and develop new tests that could be put on-line before signals begin to be transmitted back through the system.

In addition to identifying what factors the standards should measure and whether factors are grade-determining, non-grade-determining, or official criteria, the way the standards are implemented can also have a dramatic impact on grain quality. **One of the major problems facing the United States in terms of grain quality—whether physical, sanitary, or intrinsic—is that all grain, no matter the quality, is accepted into the system and marketed.** This places enormous strain on the system's handling and inspection capabilities and is the cause of most of the blending controversies.

Conclusions

The production and marketing of grain in the United States is a highly interdependent system of activities. Any policy designed to enhance grain quality—physical, sanitary, or intrinsic—must address this interdependence. Traditional policy discussions, however, have focused on only one component—grain standards. But a properly functioning market can solve many grain quality problems. Therefore, a fundamental policy alternative would be one that creates an environment that would improve market efficiency. In addition, appropriate quality information must be provided so that relevant incentives and disincentives can be established to improve market efficiency.

Evaluating policy options in terms of their strengths and weaknesses as well as their interdependence is a complex task. **One possible policy path that maximizes the strengths of the various options as well as minimizes their weaknesses is to adopt variety identification/categorization, increase the differentials in loan policy and specify minimum quality for farm loans, and introduce mandatory USGSA inspection in conjunction with NIST equipment approval.**

Introducing a variety identification scheme would improve information on intrinsic quality characteristics, thus reducing the pressure on grain standards to measure intrinsic performance in the market. For most grains, variety indicates quality better than selected tests do. The increased information resulting from variety identification would raise the efficiency of the market, resulting in incentives/disincentives being transmitted to producers, breeders, handlers, and end users. Variety identification alone, however, does not address physical or sanitary quality concerns, which must be tackled in other areas.

Removing the distortion created by the current administration of premiums and discounts for loan forfeitures and applying the same rules to country and terminal elevators storing government grain would allow the market—which has already established premiums and discounts—to function properly. Grain of lower value would be forced onto the market as opposed to entering government programs. To the extent that intrinsic quality characteristics are included, variety development would be affected. Signals from government programs would be directly transmitted to farmers that would affect their decisions on varieties planted, thus influencing breeders' objectives and release criteria.

Setting minimum quality specifications for loans places an additional constraint on entry into the loan program. These could easily be applied to physical and sanitary quality characteristics as well as measurable intrinsic characteristics and, along with the variety identification scheme, would reinforce signals being transmitted throughout the system. Farmers would be required to obtain testing of grain that was going into the loan program and being stored on farm, rather that self-certifying quality as is presently the case.

Implementing such policies on government programs and minimum quality specifications could force lower quality grain into the export market. **Therefore, minimum quality specifications established for entry into government programs could be applied to grain entering export elevators.** This would transmit signals for improved quality throughout the system and would reduce the spread of qualities available for blending at export locations.

The need for accurate measurement of important characteristics—whether physical, sanitary, or intrinsic—is crucial to providing information for the market to function properly. The vehicle by which quality information is transmitted throughout the system is grain standards. Incentives and disincentives cannot be established unless accurate, consistent, and timely information is provided in the market. **This can be accomplished by continued efforts to incorporate the four objectives of grain standards, by implementing mandatory inspection, and by increasing NIST involvement in approving grain sampling and testing equipment.**

Mandatory inspection of railcars and barges would ensure that consistent sampling and testing were performed. Used in conjunction with minimum quality specifications on grain entering export elevators, this would ensure that one government agency was responsible for testing quality. The increased presence of NIST in approving grain sampling and testing equipment would ensure that all parties testing grain quality used approved equipment and followed basic user requirements.

Grain quality is a function of the variety planted, farmer practices, environment and geographic location, handling practices, end-user preferences, marketing, government policies, and the ability of grain standards to provide information on important quality characteristics. **Present policy does not recognize the interrelatedness of these factors. Policy changes, therefore, must create an integrated policy for enhancing grain quality.**

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An Overview of the U.S. Grain System

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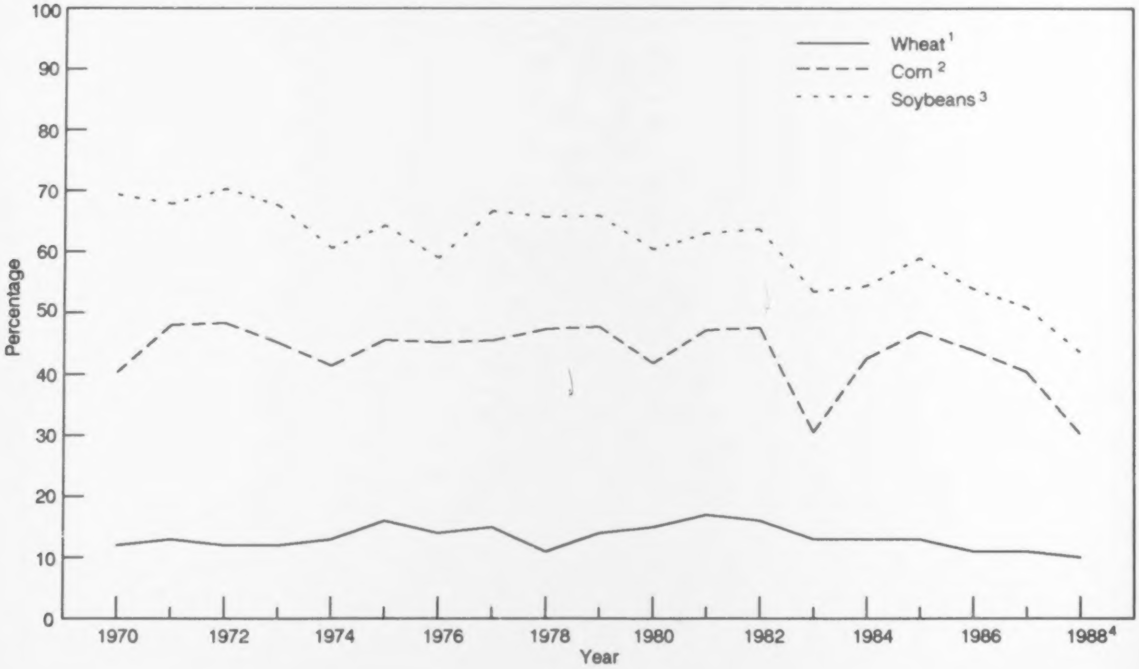
Chapter 2

An Overview of the U.S. Grain System

The United States grain industry has many characteristics that make it a formidable competitor in world markets. First, it has the capability to meet almost any demand. During the 1970s, when conditions caused a dramatic increase in demand, the Nation showed it had the productive and distributional capability to meet that demand. Second, the United States can produce almost any type of grain. Of the major grains, it is the world's largest producer of corn and soybeans and the fourth largest producer of wheat (figure 2-1). Third, a buyer can purchase nearly any type of grain at any time of the year from the United States. For many other countries this is not possible. Fourth, the Nation has the capability to move grain from farm to terminal to overseas buyer very efficiently. This is because of the extensive interstate highway system, rail system, and waterways. In addition, its high-volume, high-speed elevator facilities—both inland and export—are as efficient as any in the world.

Figure 2-1.—U.S. Share of World Wheat, Corn, and Soybean Production, 1970-88 (percentage)



SOURCES:

[1] **1970-83:** S. Evans, "Wheat: Background for 1985 Farm Legislation," Agriculture Information Bulletin No. 467, U.S. Department of Agriculture (USDA), Economic Research Service (ERS), Washington, DC, 1984;
1984-88: USDA, Foreign Agricultural Service (FAS), "World Grain Situation and Outlook," Circular Series FG 10-88, Washington, DC, October 1988.

[2] **1970-81:** USDA, ERS, "Corn, Background for 1985 Farm Legislation," Information Bulletin No. 471, Washington, DC 1984;
1982-88: USDA, FAS, "World Grain Situation and Outlook," Circular Series FG 10-88, Washington, DC, October 1988.

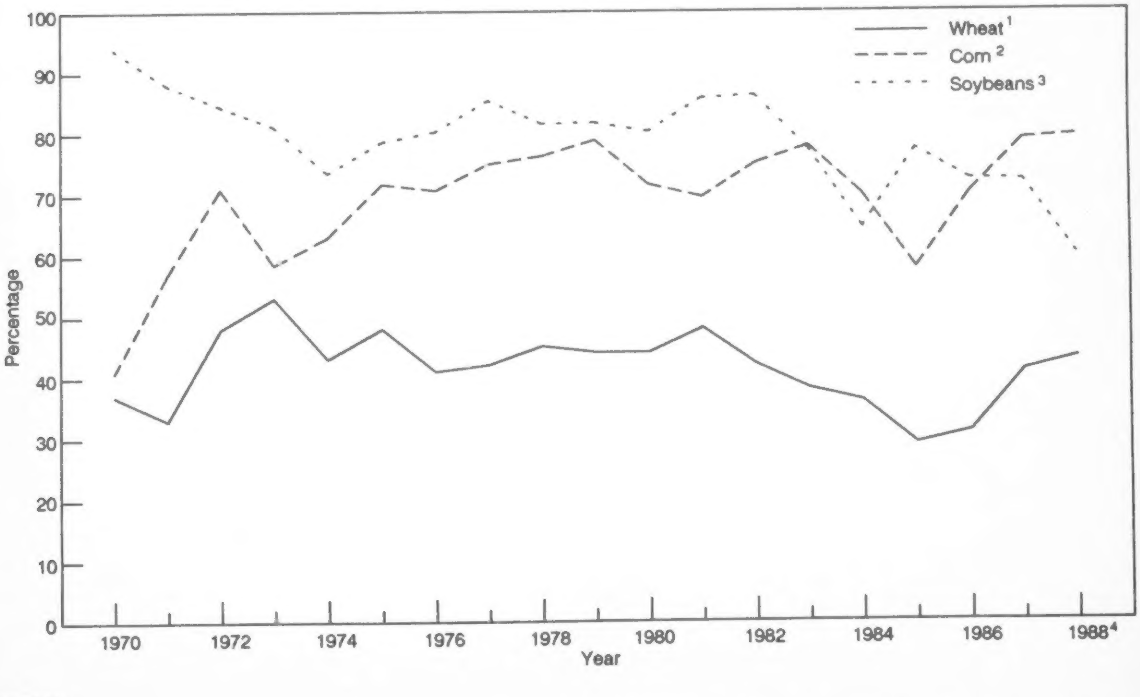
[3] **1970-81:** USDA, ERS, "Soybeans, Background for 1985 Farm Legislation," Agriculture Information Bulletin No. 472, Washington, DC, 1984;
1982-88: USDA, FAS, "World Oilseed Situation and Market Highlights," Circular Series FOP 10-88, Washington, DC, October 1988.

[4] As of October 1988.

Notwithstanding all these strengths, the ability of the United States to compete in world markets has been called into question recently. Such a question would have seemed absurd 10 years ago when the value and volume of U.S. grain and oilseed exports increased enormously. The U.S. share of world markets seemed secure (figure 2-2); the value of agricultural exports more than doubled in real terms between 1970 and 1980, with the real value of U.S. grain exports more than tripling. Agricultural exports were considered the bright spot in the generally poor U.S. trade performance across all economic sectors. In 1981, however, wheat, corn, and soybean exports fell sharply while slow but consistent growth in imports of a large variety of agricultural products continued unabated. By 1986, the Nation's export and net trade position had almost returned to 1970 levels. The U.S. agriculture industry confronted the possibility that it might face the kind of trade problems that had plagued the steel, automobile, and semiconductor industries. One congressional attempt to respond to this situation was the Grain Quality Improvement Act of 1986.

A number of factors have been listed by trade experts as causing the decline in agricultural exports, including global recession, the strong U.S. dollar, high price-support levels, European Economic Community restrictions, and increased world productive capacity. However, another factor emerging is grain quality and

Figure 2-2.—U.S. Export Market Shares in Wheat, Corn, and Soybeans, 1970-88 (percentage)



SOURCES:

[1] **1970-83:** S. Evans, "Wheat: Background for 1985 Farm Legislation," Agriculture Information Bulletin No. 467, U.S. Department of Agriculture (USDA), Economic Research Service (ERS), Washington, DC, 1984;
1984-88: USDA, Foreign Agricultural Service (FAS), "World Grain Situation and Outlook," Circular Series FG 10-88, Washington, DC, October 1988.

[2] **1970-81:** USDA, ERS, "Corn, Background for 1985 Farm Legislation," Information Bulletin No. 471, Washington, DC 1984;
1982-88: USDA, FAS, "World Grain Situation and Outlook," Circular Series FG 10-88, Washington, DC, October 1988.

[3] **1970-81:** USDA, ERS, "Soybeans, Background for 1985 Farm Legislation," Agriculture Information Bulletin No. 472, Washington, DC, 1984;
1982-88: USDA, FAS, "World Oilseed Situation and Market Highlights," Circular Series FOP 10-88, Washington, DC, October 1988.

[4] As of October 1988.

its use as a competitive tool in international markets. The factors listed above are considered the major contributors to the decline in world market share. But as the dollar weakens and lower price-support levels take effect, allowing U.S. exports to become more price-competitive, opportunities to increase exports may be hampered by foreign buyers' concerns about U.S. grain quality.

Importers of U.S. grain have become more vocal in their concern about quality. Formal complaints made by buyers to the U.S. Department of Agriculture (USDA) have increased yearly. In 1987 over 60 complaints concerning quality were received at USDA. This number is a conservative estimate of the true concern since the amount of paperwork involved discourages the filing of complaints. Examples of specific complaints include: excessive amounts of material other than grain in the shipment; quality attributes, such as wheat protein, not meeting contract specifications; grain (mainly corn and soybeans) arriving out of condition, e.g., moldy or infested; and grain arriving in a broken or cracked condition.

This report focuses on the enhancement of grain quality. To put that issue in perspective, it is important to understand how the U.S. grain system operates. The following sections provide an overview of grain production, end uses, export markets, grain flow, Government programs, and quality control, which are described in the rest of this assessment. The chapter ends with a discussion of the quality issue and a definition of quality.

GRAIN PRODUCTION

Production trends in the United States from 1971 to 1986 are shown in table 2-1. Annual wheat production averaged 1.7 billion bushels during the first 4 years of this period. By 1979, yearly production had increased to 2.1 billion bushels, and it peaked at 2.8 billion bushels by 1981. Overall, wheat production has increased 29 percent since 1971.

From 1971 to 1975, corn production averaged 5.5 billion bushels per year. Production increased to 7.9 billion bushels by 1979. In 1983, corn production was drastically reduced as a result of the payment-in-kind program. But in 1985, it peaked at 8.9 billion bushels. However, in 1988 corn production dropped to only 4.5 billion bushels because of the severe drought. Corn production overall has increased 46 percent since 1971.

Yearly soybean production averaged 1.3 billion bushels per year during the years 1971 to 1976; output peaked at 2.3 billion bushels in 1979, and stayed around 2.0 billion bushels by 1986. But it was reduced to 1.5 billion bushels in 1988 because of the drought. Overall, soybean production has increased 71 percent since 1971.

Table 2-1.—U.S. Wheat, Corn, and Soybean Production, 1971-88 (millions of bushels)

Year	Wheat	Soybeans	Corn
1971	1,618.6	1,176.1	5,641.0
1972	1,546.2	1,270.6	5,573.0
1973	1,170.8	1,547.5	5,647.0
1974	1,781.9	1,216.3	4,701.4
1975	2,126.9	1,547.4	5,829.0
1976	2,148.8	1,287.6	6,266.4
1977	2,045.0	1,767.0	6,425.5
1978	1,775.5	1,869.0	7,081.8
1979	2,134.1	2,268.0	7,938.8
1980	2,380.9	1,798.0	6,644.8
1981	2,785.4	1,989.0	8,201.6
1982	2,765.0	2,190.0	8,235.1
1983	2,419.8	1,636.0	4,174.7
1984	2,594.8	1,861.0	7,674.0
1985	2,425.1	2,099.0	8,876.7
1986	2,086.8	1,940.0	8,252.8
1987	2,105.0	1,905.0	7,064.0
1988*	1,821.0	1,472.0	4,462.0

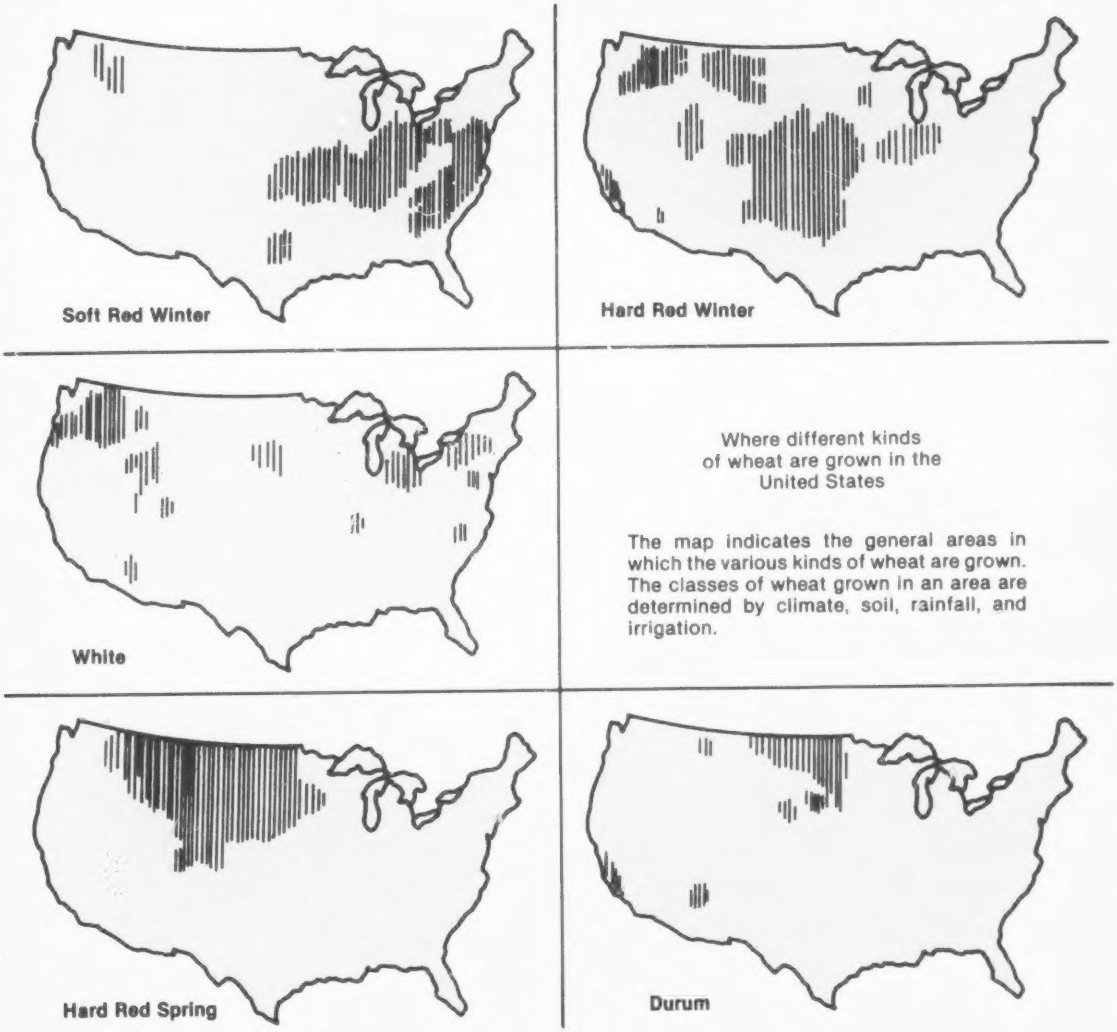
*Preliminary

SOURCE: U.S. Department of Agriculture, "Crop Production," Agricultural Statistics Board, National Agricultural Statistics Service, CrPr 2-2. Washington, DC, various issues.

Wheat

Figure 2-3 shows the general areas where various wheat types are grown. Forty-two States produce various wheat types. However, almost 42 percent is produced in just five States:

Figure 2-3.—Wheat-Producing Areas of the United States



Where different kinds
of wheat are grown in the
United States

The map indicates the general areas in which the various kinds of wheat are grown. The classes of wheat grown in an area are determined by climate, soil, rainfall, and irrigation.

SOURCE: Wheat Flour Institute, "From Wheat to Flour," revised ed., Washington, DC, 1981.

Kansas, Oklahoma, Texas, Nebraska, and Colorado. These five produce Hard Red Winter wheat—the major type grown in the United States.

About one-fourth of the wheat produced in the United States is grown in North and South Dakota, Minnesota, and Montana. These States produce Hard Red Spring wheat. Of the several other wheat types produced, Durum wheat is grown mainly in North Dakota and Montana, White wheat is grown mainly in the Pacific Northwest, and Soft Red Winter wheat is grown from Missouri to Ohio and in the Atlantic States.

Corn

Corn is produced in 47 States. The six Corn Belt States—Iowa, Illinois, Indiana, Nebraska, Minnesota, and Ohio—produced about 70 percent of the 1985 corn crop. Historically these six have been the dominant corn-producing States. Corn production in recent years, however, has increased in other parts of the country. This has been the result of new, short-season hybrid seed corn that has increased yields in Northern States like North Dakota and New York, and of Government programs that have made corn production profitable in States with relatively high production costs.

Soybeans

Soybeans are produced in 29 States. Six account for almost two-thirds of the output: Illinois, Iowa, Indiana, Missouri, Ohio, and Minnesota. In fact, Illinois and Iowa accounted for 33 percent of the total 1985 crop and were the dominant producers.

UTILIZATION

Each grain has multiple uses and is important in world markets. In this section the various uses of each will be discussed as well as the magnitude of the dependence on export markets.

Wheat

Wheat is used for domestic food consumption, export, animal feed, and seed (table 2-2). The proportion used for domestic purposes has fluctuated between 32 and 53 percent over the past 15 years. Wheat is very dependent on the export market. The export market has grown since 1971, and by the early 1980s as much as 68 percent of U.S. wheat was exported. The export market share has declined since then to less than 50 percent of total wheat use.

Almost all wheat, other than that fed directly to livestock, is milled into flour for producing a variety of bakery products for human consumption. Wheat is unique in that it is the only cereal grain with sufficient gluten content to make a loaf of bread without being mixed with another grain.

Corn

The major use for corn is domestic animal feed, accounting for well over half the corn con-

Table 2-2.—U.S. Utilization of Wheat by Type of Use, 1971-88 (million bushels and percentage)[a]

Year	Food	Seed	Animal feed	Total domestic	Domestic share (percent)	Exports	Export share (percent)
1971-72	523.7	63.2	262.4	849.3	58.2	609.8	41.8
1972-73	531.8	67.4	199.8	799.0	41.3	1,135.0	58.7
1973-74	544.3	84.1	125.1	753.5	56.1	1,217.0	43.9
1974-75	545.0	92.0	34.9	671.9	39.7	1,018.5	60.3
1975-76	588.6	99.0	38.3	725.9	38.2	1,172.9	61.8
1976-77	588.0	92.0	74.4	754.4	44.2	949.5	55.8
1977-78	586.5	80.0	192.5	859.0	43.3	1,123.9	56.7
1978-79	592.4	87.0	157.6	837.0	41.2	1,194.1	58.8
1979-80	596.1	101.0	86.0	783.1	36.2	1,375.2	63.8
1980-81	610.5	113.0	59.0	782.5	34.1	1,513.8	65.9
1981-82	602.4	110.0	134.8	847.2	32.4	1,770.7	67.6
1982-83	616.4	97.0	194.8	908.2	37.6	1,508.7	62.4
1983-84	642.6	100.0	369.1	1,111.7	43.8	1,428.6	56.2
1984-85	651.0	98.0	404.5	1,153.5	44.7	1,424.1	55.3
1985-86	678.1	93.0	273.5	1,044.6	53.3	915.4	46.7
1986-87	696.0	84.0	413.3	1,193.3	54.3	1,003.5	45.7
1987-88[b]	719.0	85.0	280.1	1,084.2	40.5	1,592.1	59.5

[a] Differences between utilization and production are attributable to imports.

[b] Preliminary.

SOURCE: U.S. Department of Agriculture, "Wheat Situation and Outlook Report," Economic Research Service, Washington, DC, various issues.

sumed in the United States (table 2-3). Feed use has fluctuated with prices and livestock inventory. Other domestic uses include food/industrial use and seed. Industrial use has shown steady growth since 1971. Total domestic corn usage has accounted for 70 to 85 percent of usage over the past 15 years. Corn is not as dependent as wheat on world markets, but as much as 30 percent of total usage is exported in some years.

Feed grains, which include corn, are characterized as high-energy grains due to their relatively high levels of nitrogen-free extract (principally starch) and low levels of crude fiber (4). Nearly all feed grains are highly palatable to livestock. Corn is the leader in the amount of energy contained. However, several byproducts from corn used by food manufacturers are also available for animal feed. These include such products as corn gluten feed and meal, Brewer's dried grains, and distiller's dried grains.

Corn is prepared for human consumption and industrial use by dry and wet mill processing. Dry milling is the process by which corn is separated into components of hulls, germs, and endosperm. Two processes are used: tempering-degerming and alkaline dry milling. These produce flaking grits for breakfast cereals, baking, and the snack food industries.

More than half the corn starch manufactured from the wet milling process is converted into corn syrups and corn sugar. Corn starches and sugars are used for human foods, beverages, industrial products, and livestock feeds. Corn syrup is used in human foods, beverages, and industrial products. Crude corn oil, which is extracted during starch recovery, is used for human food, industrial products, and animal feed. The water used to soak the corn, commonly referred to as steepwater, is used in pharmaceuticals and liquid animal feed.

Soybeans

Soybeans are processed for domestic food and feed consumption, used for seed, and exported. Domestic processing is the most important use of soybeans and has increased steadily over the past 15 years (table 2-4). Domestic soybean utilization has accounted for approximately 60 percent of total usage, while the export market has accounted for about 40 percent.

Soybeans are primarily used for oil extraction. The residuals from this process are toasted and ground into a high-protein meal for use as a supplement in animal feed. Other soybean uses include lecithin, soy flour, and soy grits. Soybean meal usage, like corn, has increased

Table 2-3.—U.S. Utilization of Corn by Type of Use, 1971-88 (million bushels and percentage)[a]

Year	Food, alcohol, and industrial	Seed	Animal feed	Total domestic	Domestic share (percent)	Exports	Export share (percent)
1971-72	394.0	15.0	3,978.0	4,387	84.8	786.0	15.2
1972-73	407.0	16.0	4,310.0	4,733	79.2	1,243.0	20.8
1973-74	417.0	18.0	4,265.0	4,700	79.8	1,188.0	20.2
1974-75	432.6	18.8	3,225.6	3,677	76.2	1,148.5	23.8
1975-76	469.9	20.2	3,591.6	4,081.7	70.5	1,711.4	29.5
1976-77	493.3	19.8	3,586.6	4,099.7	70.9	1,684.2	29.1
1977-78	532.9	18.0	3,709.5	4,260.4	68.6	1,947.8	31.4
1978-79	557.0	18.0	4,198.1	4,773.1	69.1	2,133.1	30.9
1979-80	655.1	20.0	4,518.6	5,193.7	68.1	2,432.6	31.9
1980-81	715.1	20.2	4,139.0	4,874.3	67.4	2,355.2	32.6
1981-82	792.1	19.4	4,276.0	5,087.5	72.1	1,966.9	27.9
1982-83	880.3	14.5	4,520.7	5,415.5	74.7	1,833.8	25.3
1983-84	956.0	19.1	3,817.6	4,792.7	71.6	1,901.5	28.4
1984-85	1,070.0	21.2	4,079.0	5,170.2	73.5	1,865.4	26.5
1985-86	1,140.0	19.5	4,095.3	5,254.8	80.9	1,241.2	19.1
1986-87	1,175.0	16.7	4,713.7	5,905.4	79.7	1,504.4	20.3
1987-88	1,207.0	17.0	4,649.7	5,873.7	77.3	1,725.0	22.7

[a] Differences between utilization and production are attributable to imports.

SOURCE: U.S. Department of Agriculture, "Feed Situation and Outlook," Economic Research Service, Washington, DC, various issues.

Table 2-4.—U.S. Utilization of Soybeans by Type of Use, 1971-88 (million bushels and percentage)[a]

Year	Domestic processing	Seed, feed, and residual	Total domestic	Domestic share (percent)	Exports	Export share (percent)
1971	720	65	785	65.3	417	34.7
1972	722	82	804	62.7	479	37.3
1973	821	75	896	62.4	539	37.6
1974	701	79	780	64.9	421	35.1
1975	865	71	936	62.8	555	37.2
1976	790	76	866	60.6	564	39.4
1977	927	82	1,009	59.0	700	41.0
1978	1,018	99	1,117	60.2	739	39.8
1979	1,123	85	1,208	58.0	875	42.0
1980	1,020	99	1,119	60.7	724	39.3
1981	1,030	89	1,119	54.6	929	45.4
1982	1,108	86	1,194	56.9	905	43.1
1983	983	79	1,062	58.8	743	41.2
1984	1,030	93	1,123	65.3	598	34.7
1985	1,053	86	1,139	60.6	740	39.4
1986	1,179	104	1,283	62.9	757	37.1
1987	1,170	96	1,266	61.7	785	38.3
1988[b]	1,075	95	1,170	65.2	625	34.8

[a] Differences between utilization and production are attributable to imports.

[b] Preliminary.

SOURCE: U.S. Department of Agriculture, "Oil Crops Situation and Outlook Report," Economic Research Service, Washington, DC, various issues.

relative to livestock inventory. Overall, soybean meal usage has increased 49 percent since 1970.

Export Markets

The United States is quite dependent on world markets, which are constantly changing in response to new relationships between buyers and sellers.

Wheat exports increased dramatically in 1972 and from 1976 to 1982. Overall, wheat exports increased about 190 percent during the decade from 1971 to 1981 and have declined by almost 50 percent since then.

The markets for U.S. wheat have shifted over time. The major importers in 1970 were India, Western Hemisphere countries, Japan, the European Community (EC), and South Korea (table 2-5). By 1985, exports to India and the EC had declined sharply. The major importers were Western Hemisphere countries and Japan (same markets) and the African countries (new markets). During this time the Soviet Union (U.S.S.R.) was a sporadic buyer—but a large one.

Corn exports increased dramatically from 1971 to 1981. During that time exports increased by 200 percent, but since then they have declined by 47 percent. In 1970, the largest importers of U.S. corn were the EC and Japan (table 2-6). By 1985, the EC share had dropped to 10 percent and the largest importers were Japan and the U.S.S.R. Other areas that had steady growth during this time were the Western Hemisphere, the Middle East countries, and South Korea.

The growth of soybean export markets followed the same path as wheat and corn. During the 1971-81 period, U.S. soybean exports increased 123 percent. Since then exports have declined by 25 percent. Compared with wheat and corn, the decline in soybeans was the smallest.

The major soybean markets have not changed since 1970 (table 2-7). The largest importers have been the EC and Japan, accounting for approximately 65 percent of the U.S. soybean export market. Taiwan, Eastern Europe, Israel, and Western Hemisphere countries have been steady importers, but imports by other West European countries have been declining throughout the period.

Table 2-5.—Distribution of U.S. Wheat Exports by Destination, 1970-86 (in percent)

Years	Western Hemisphere	Europe	Middle East oil-exporting countries	USSR	Japan	South Korea	Pakistan	India	Africa	China	Other	Total
1970-71	17.4	11.3	0.1	0	14.0	10.0	6.1	15.6	7.0	0	18.5	100
1971-72	13.7	23.7	2.0	0	15.6	9.0	3.5	7.4	8.0	0	17.1	100
1972-73	19.1	12.7	4.6	0	13.4	9.2	5.9	5.8	11.7	0.5	17.1	100
1973-74	14.5	13.1	2.1	30.6	10.9	5.2	3.6	1.2	5.6	7.9	5.3	100
1974-75	19.3	10.9	4.4	9.2	10.3	5.5	1.8	5.5	11.5	9.0	12.6	100
1975-76	14.9	10.4	7.6	3.6	12.0	5.9	3.3	14.3	10.7	0.5	16.8	100
1976-77	17.4	16.0	1.7	12.3	10.2	4.5	2.1	15.5	10.7	0	9.6	100
1977-78	13.2	12.8	8.4	10.8	11.4	7.4	0.7	9.1	16.4	0	9.8	100
1978-79	19.6	15.0	6.7	10.7	11.6	5.7	2.0	1.0	17.4	3.0	7.3	100
1979-80	17.3	14.4	5.2	9.0	10.2	5.0	3.8	0.1	14.9	7.7	12.4	100
1980-81	20.0	19.3	1.8	6.2	9.5	5.0	0.6	0.8	13.0	11.2	12.6	100
1981-82	20.2	10.2	3.3	5.0	8.5	4.9	0.4	1.2	13.1	18.4	14.8	100
1982-83	18.1	9.1	1.6	13.2	7.4	4.2	0.5	2.7	13.5	18.3	11.4	100
1983-84	17.6	4.4	2.7	8.7	9.5	5.4	0.5	9.6	14.8	10.2	16.6	100
1984-85	17.5	5.6	2.7	18.1	8.2	4.8	0.3	2.7	16.2	10.6	13.3	100
1985-86	23.7	5.9	2.0	9.6	11.2	6.4	1.4	0.1	18.9	4.6	16.2	100

SOURCE: U.S. Department of Agriculture, "Grain and Feed Market News," Agricultural Marketing Service. Washington, DC, various issues

Table 2-6.—Distribution of U.S. Corn Exports by Destination, 1970-86 (in percent)

Year	Western Hemisphere	European Community	Other Western Europe	Eastern Europe	Middle East oil exporting countries	USSR	Japan	South Korea	China	Other	Total
1970-71	4.7	58.6	0	7.4	0	10	26.0	2.0	0	1.2	100
1971-72	2.9	42.3	3.4	6.9	0.1	11.8	13.8	2.7	0	16.1	100
1972-73	6.5	33.8	7.0	6.3	0.1	12.9	18.0	1.4	4.0	10.0	100
1973-74	9.9	31.8	7.5	5.4	0.1	13.2	20.0	1.2	4.2	6.7	100
1974-75	10.1	40.7	10.3	10.9	0.5	4.1	17.5	1.4	0	4.7	100
1975-76	5.8	30.0	7.6	11.1	0.2	24.8	13.6	1.4	0	5.5	100
1976-77	5.0	43.3	5.9	11.5	0.5	10.0	16.5	2.2	0	5.1	100
1977-78	6.9	27.3	8.1	10.1	0.6	20.5	17.2	3.6	0	5.7	100
1978-79	7.9	24.7	6.3	11.0	0.6	16.1	16.8	5.9	5.4	5.3	100
1979-80	13.3	21.3	8.8	12.0	0.4	9.5	18.3	3.5	2.9	10.0	100
1980-81	16.9	18.0	9.6	11.8	0.2	8.0	22.2	3.9	1.2	8.2	100
1981-82	10.3	15.7	13.0	6.5	0.1	14.5	21.5	5.1	2.6	10.7	100
1982-83	13.6	20.1	0.2	2.9	0.3	7.0	28.5	8.9	4.6	13.9	100
1983-84	11.0	17.5	0.1	1.3	0.9	13.8	30.1	6.2	0	19.1	100
1984-85	6.3	13.1	0.1	1.6	1.2	32.7	23.1	2.8	0	19.2	100
1985-86	11.2	10.1	0	3.1	1.8	21.4	29.9	4.4	0	18.1	100

SOURCE: U.S. Department of Agriculture, "Grain and Feed Market News," Agricultural Marketing Service, Washington, DC, various issues.

GRAIN FLOW

The major tasks of the United States grain industry are to assemble grain from farmers, combine it in their facilities according to quality differentiations, store it until it is sold, and transport it by the most cost-effective means to the final market destination.

Farmers transport grain from the farm in farm-tractor wagons or trucks to country elevators, subterminal or terminal elevators, export elevators, or domestic processors (figure 2-4). From some locations, farmers can deliver grain directly to Canada from the farm by truck.

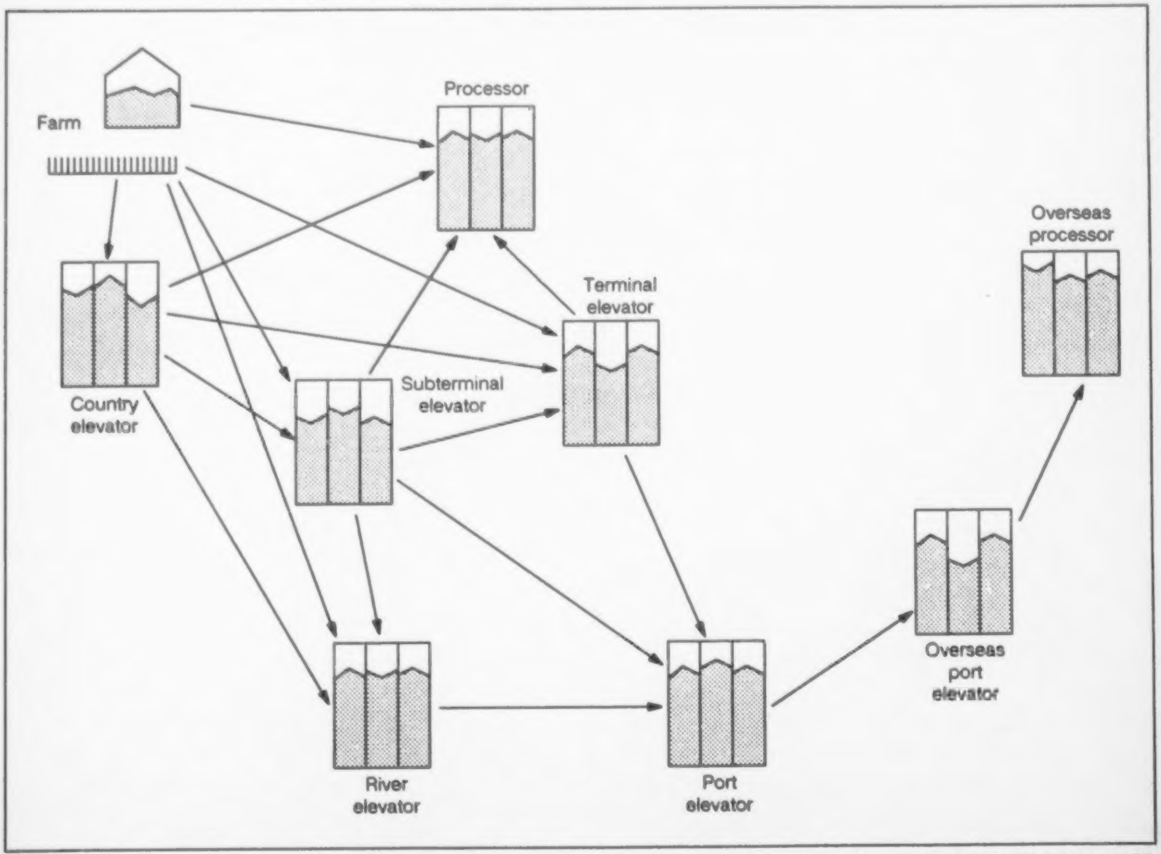
Domestic processors and export elevators can receive grain straight from farmers who are located within the general vicinity. When sufficient quantities cannot be supplied by local

Table 2-7.—Distribution of U.S. Soybean Exports by Destination, 1970-86 (in percent)

Years	Western Hemisphere	European Community	Other Western Europe	Eastern Europe	Japan	Israel	Taiwan	Other	Total
1970-71	10.3	43.4	11.8	1.4	24.2	2.8	4.7	1.4	100
1971-72	8.0	42.1	11.9	0.6	23.8	2.9	5.4	5.3	100
1972-73	5.8	44.8	8.6	1.3	25.3	2.5	4.1	7.6	100
1973-74	10.1	46.9	10.4	0.9	20.9	2.6	3.8	4.4	100
1974-75	7.5	44.1	13.2	1.2	22.7	3.5	6.6	1.2	100
1975-76	5.5	47.8	7.9	0.3	21.5	2.5	5.2	9.3	100
1976-77	7.8	46.1	6.1	0.4	20.2	2.6	4.8	12.0	100
1977-78	7.3	47.1	3.9	4.0	20.1	2.1	4.9	10.6	100
1978-79	5.8	42.2	6.6	0.4	19.2	1.9	5.8	18.1	100
1979-80	5.5	46.0	10.3	5.7	17.0	1.8	3.1	10.6	100
1980-81	9.3	43.6	9.1	4.1	19.7	1.8	5.2	7.2	100
1981-82	6.2	46.8	14.1	1.7	16.2	1.7	4.6	8.7	100
1982-83	8.2	56.0	1.2	2.4	20.5	1.8	4.9	5.0	100
1983-84	9.0	46.5	1.1	3.3	22.8	2.8	6.5	8.0	100
1984-85	10.5	44.1	0.9	2.3	24.8	2.5	7.8	7.1	100
1985-86	6.7	44.1	0.6	2.5	21.8	1.9	7.5	14.9	100

SOURCE: U.S. Department of Agriculture, "Grain and Feed Market News," Agricultural Marketing Service, Washington, DC, various issues.

Figure 2-4.—Grain Flow From Farm to Final Destination


Farm
Processor
Country elevator
Subterminal elevator
Terminal elevator
Overseas processor
River elevator
Port elevator
Overseas port elevator

SOURCE: U.S. Department of Agriculture, "The Physical Distribution System for Grain," Office of Transportation, Agriculture Information Bulletin No. 457, Washington, DC, October 1983.

farmers, domestic processors and export elevators obtain grain from other sources. This is accomplished by a system of country, subterminal, and terminal elevators used to collect, store, and move grain through the system to its ultimate destination.

In many cases, grain destined for export is delivered by the farmer to the country elevator, unloaded and stored, loaded, and delivered to a subterminal elevator. Here again the grain is unloaded and stored. At subterminal elevators, it can be loaded and shipped to export elevators or terminal elevators. If subterminal elevators do not deliver the grain to its final destination, then it is delivered to a terminal elevator, unloaded, stored, and reloaded for shipment to a port. Once grain is received at an export elevator, it is unloaded and loaded onto the vessel for shipment to the importing country within a very short period of time. At export elevators the emphasis is on throughput capacity with minimal storage. At interior elevators the reverse is true, with the emphasis being on increased storage capacity and reduced handling capacity.

Grain moves by truck, railroad, barge, or ship or any combination of these modes as it makes its way from the farm to its final destination. The reported quantities of grain moved by railroads and barges is shown in table 2-8. The share by rail ranged from a high of 80.3 percent in 1974 to a low of 66 percent in 1982. Barge shares tend to rise and fall as exports increase or decrease, primarily because almost all grain moving by barge is destined for export ports in the New Orleans area. The rail share of grain moving to export ports declined from 62 percent in 1974 to 38 percent in 1983 (1). Except for the relatively small amount of grain moving into Canada by truck and into Mexico by rail, ocean vessels carry almost all exported grain.

Table 2-8.—Quantity of Grain Hauled by Rail and Barges, 1974-85

Year	Quantity moved (billion bushels)		Share moved (percent)	
	Rail	Barges	Rail	Barges
1974	4.21	1.03	80.3	19.7
1975	4.06	1.20	77.3	22.7
1976	4.10	1.61	71.8	28.2
1977	3.91	1.52	72.0	28.0
1978	4.12	1.63	71.7	28.3
1979	4.41	1.62	73.1	26.9
1980	5.00	1.91	72.4	27.6
1981	4.38	1.99	68.8	31.2
1982	4.22	2.18	66.0	34.0
1983	4.72	2.11	69.1	30.9
1984	4.81	1.97	70.9	29.1
1985	3.99	1.67	70.5	29.5

SOURCE: Association of American Railroads. *The Grain Book 1986* (Washington, DC: 1987).

STORAGE AND HANDLING

Grain handling and storage systems have developed over the years to provide an economical means of moving grain into storage, preserving its quality while in storage, and unloading it from storage. The total U.S. grain storage capacity in 1987 was 23 billion bushels (5), of which 14 billion bushels was on-farm storage and 9 billion was considered off farm.

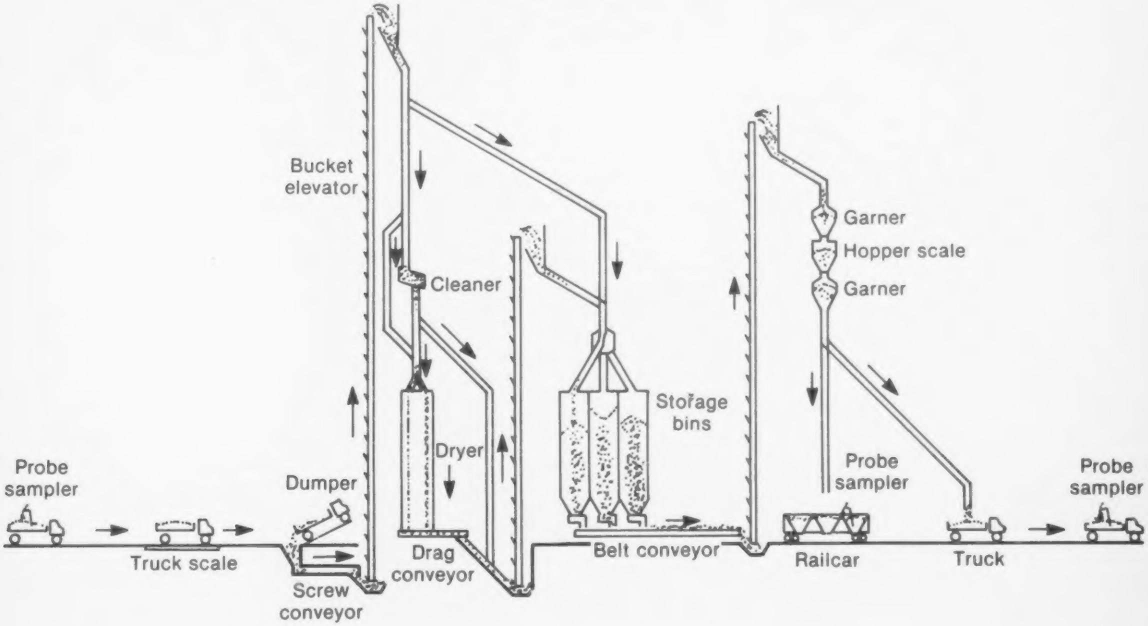
Regardless of whether storage and handling systems are constructed on farm or off, basic types of equipment are being used. The only differences are in the choice of the number and types of equipment, size, capacity, and configuration.

The basic storage types can be categorized as upright metal bins or concrete silos, flat warehouses (buildings), and on-ground (piles). Upright bins and concrete silos are the most easily managed type and can be found on farms as well as in commercial facilities. They range in size from farm bins as small as 3,000 bushels to over 500,000 bushels in commercial facilities. These storage types are loaded from the top and easily unloaded from the bottom. In most instances, they can be equipped with aeration to maintain cool grain temperatures, easily sealed for fumigation when required, and, depending on the number of bins available, unloaded and turned if needed.

The recent demand for additional storage space has increased the use of flat warehouses, of on-ground piles placed on hard surfaces confined by movable sloping walls or circular rings, and of several other forms of on-ground piling. These storage types are more difficult to load, unload, fumigate, and aerate than upright bins. In the fall of 1986, approximately 300 million bushels of grain were stored in piles. By the summer of 1987 this volume had doubled, to over 600 million. Most was corn and, to a lesser extent, wheat (5).

Considerable interactions occur between handling and storage technologies based on the size and type of storage structures in use. Certain kinds of handling equipment are well suited to high-speed, high-volume upright elevators; others, to flat storage or to on-farm storage. Various types of handling equipment are used to move grain horizontally or vertically within farm or commercial facilities. Figures 2-5 and 2-6 show basic flow diagrams of terminal and export elevators. Country elevators could have less equipment than shown in figure 2-5, and export elevators may have cleaners on the outbound side. Therefore, these figures only provide basic configurations and should not be taken as being representative of all grain elevators.

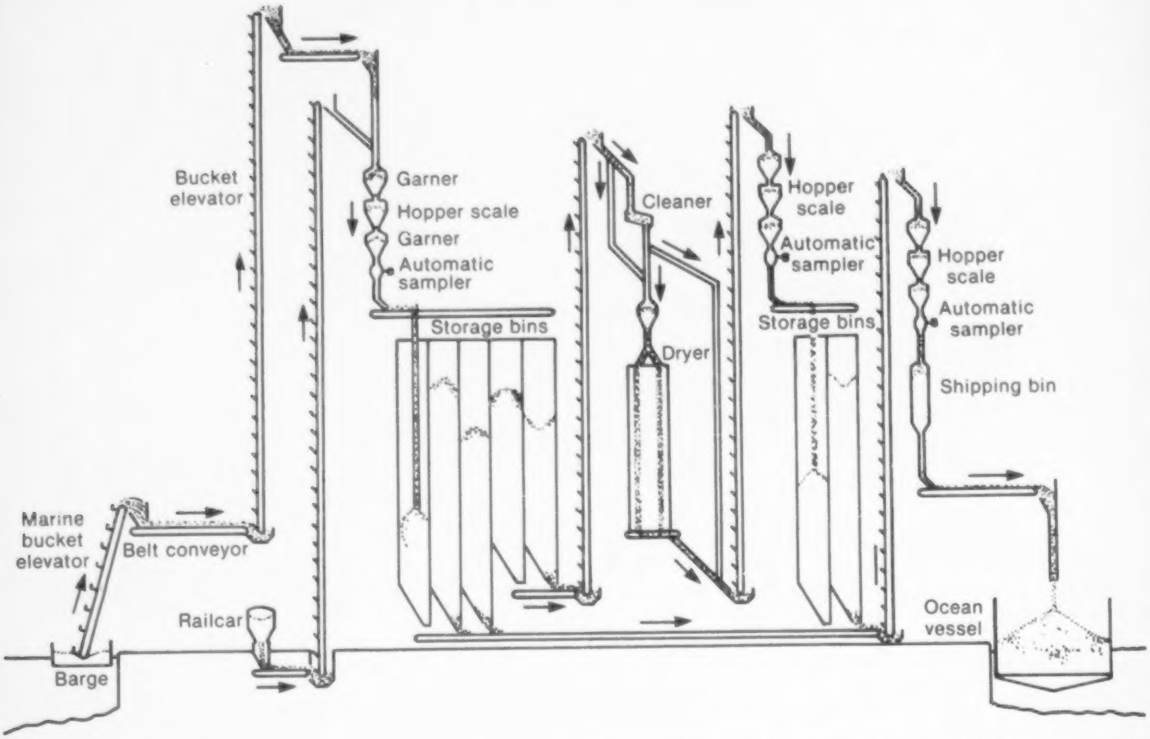
Figure 2-5.—Flow of Grain Through the Country Elevator



Bucket elevator
Cleaner
Garner
Hopper scale
Garner
Storage bins
Dryer
Probe sampler
Dumper
Probe sampler
Probe sampler
Truck scale
Screw conveyor
Drag conveyor
Belt conveyor
Railcar
Truck

SOURCE: U.S. Department of Agriculture, "The Physical Distribution System for Grain," Office of Transportation, Agriculture Information Bulletin No. 457, Washington, DC, October 1983.

Figure 2-6.—Flow of Grain Through the Export Elevator


Bucket elevator
Garner
Hopper scale
Garner
Automatic sampler
Storage bins
Cleaner
Dryer
Hopper scale
Automatic sampler
Storage bins
Hopper scale
Automatic sampler
Shipping bin
Marine bucket elevator
Belt conveyor
Railcar
Barge
Ocean vessel

SOURCE: U.S. Department of Agriculture, "The Physical Distribution System for Grain," Office of Transportation, Agriculture Information Bulletin No. 457, Washington, DC, October 1983.

MARKETING OF GRAIN

A fundamental principle of the U.S. grain marketing system is that of self-selection. Producers, handlers, and users all act in their own best interests. Producers select varieties and make other agronomic decisions with the objective of maximizing profit. Handlers assemble, condition, and deliver grain subject to negotiated contract terms with the objective of maximizing profit. And users select among different qualities available, each with a different end-use characteristic, also with the objective of maximizing profit.

The market for quality characteristics is central to these decisions. Through this market, price differentials develop that provide incentives and disincentives for participants throughout the system. An important aspect of this process is that premiums and discounts, and therefore incentives and disincentives, develop for quality characteristics. Bargaining and contracting for quality specifications occurs throughout the system, explicitly and implicitly, between buyers and sellers. The premiums and discounts built into contracts reflect value to the participants.

From an operational perspective, farmers typically sell and deliver grain to local country elevators for a cash price. Farmers' decisions on where to sell their grain are sometimes based simply on selling to the closest elevator or the one they have always sold to before. Since the middle 1960s, however, farmers have increasingly searched for bids at competing elevators located as far as 40 or more miles away. They subtract the cost of delivery from the bid price at each elevator and then deliver to the one from which they receive the highest net bid.

After buying from farmers, the country elevator manager, like many farmers, also decides when and where to sell the grain to processors or exporters based almost entirely on the highest available net bid. Typically, elevators will switch shipments from one destination to another for a fraction of a cent per bushel. In this highly competitive setting, participants are almost certain to adopt innovations in technology, services, and transportation quickly. Gains that accrue to an innovator through cost-reducing procedures soon become apparent to competing firms through changing prices and a shift of grain away from their firm. This, in turn, forces neighboring firms to adopt the innovation or accept a declining volume of business.

Country elevators typically hedge their grain purchases from farmers by selling a futures contract for a similar quantity on the Chicago Board of Trade. When country elevators sell their grain directly or through a broker to grain processors, exporters, or cash merchandisers, the country elevator "lifts" the hedge by buying back a futures contract for a similar quantity from the Chicago Board of Trade. The hedge protects the elevator from the large price risks associated with changes in international grain supplies and demands. In exchange, the elevator receives the smaller price risk from the "basis"—that is, the difference between the appropriate Board of Trade futures contract price and the local price of grain. Almost all participants in the grain trade—except speculators at the Chicago Board—hedge their purchases and sales in a similar manner.

The sales contract between the country elevator and the processor, exporter, or cash merchandiser typically specifies the terms of the sale. Unless otherwise specified in the contract, title and risk of loss or damage on domestic sales pass to the buyer as follows:

- on f.o.b. (free on board) contracts, at the moment of acceptance of the appropriate shipping document by the courier, and
- on delivered contracts, when the shipment is constructively placed or otherwise made available at the buyer's original destination (2).

Thus, the buyer is responsible for loss or damage during transit on f.o.b. sales and the seller is responsible for loss and damage during transit on delivered contracts.

Export sales are typically made directly between exporting firms and importing country buyers. In centrally planned countries, the buyer is a government agency; in most other countries, the buyer is typically a merchandiser or buying agency who buys grain and resells it to end users in the importing country.

Most U.S. export sales are made under terms specified in North American Export Grain Association, Inc. (NAEGA) contract forms. Industry sources indicate that at least half of U.S. grain export sales are made under terms specified in the NAEGA f.o.b. contract. This contract specifies that:

1. the quality and condition to be final at port of loading in accordance with official inspection certificates,
2. seller shall retain title to the commodity until seller has been paid in full, it being understood that risk of loss shall pass to buyer at discharge end of loading spout (3).

Therefore, the seller retains title of the grain until paid, but the buyer assumes all risk once the grain leaves the discharge end of the loading spout at the export elevator.

GOVERNMENT FARM POLICY

The main purpose of government farm policy is to support farm incomes. Several different policies and program mechanisms have been used over time to achieve this. The two main programs are the loan rate and deficiency payment/target price.

Loan Program

The Commodity Credit Corporation (CCC) makes nonrecourse loans to farmers at established loan rates for a variety of crops, including corn, wheat, and soybeans. The loan, plus interest and storage, can be repaid within 9 to 12 months and the commodity sold on the cash market. If it is not profitable for the farmer to repay the loan, CCC has no recourse but to accept the commodity in full payment of the loan. Commodity loans are frequently referred to as a price support, since national season-average prices generally do not fall below set loan levels.

The major objective of the loan program is to add price stability to the market by releasing CCC stocks when prices are high and withdrawing them when prices are low. A second objective is to encourage orderly marketing of commodities throughout the year by preventing a glut at harvest.

Deficiency Payment/Target Price Program

In the United States, deficiency payments are paid to farmers to make up the difference between a price determined to be a politically acceptable income level (target price) and the higher of the average market price or the loan rate. Deficiency payments are made on each farm's actual planted acres and farm program yield. The farm program yield is based on each farm's yield history. Deficiency payments were initiated to raise and stabilize farmer incomes, while allowing farm prices to be competitive in the export market.

QUALITY CONTROL

The United States Grain Standards Act (USGSA), administered by the Federal Grain Inspection Service (FGIS), is the statutory authority for developing grain standards. The Declaration of Policy contained in Section 2 of the USGSA states that it is Congress' intent that uniform standards for promoting and protecting grain moving in interstate and foreign commerce be developed so that grain can be marketed in an orderly and timely manner and that trading in grain may be facilitated.

Standards for wheat, corn, barley, oats, rye, sorghum, flaxseed, soybeans, triticale, sunflower seed, and mixed grain have been promulgated under the USGSA by FGIS. Each standard consists of numerical grades, i.e., 1, 2, 3, and Sample Grade. Factors are included in each standard and maximum limits for each factor have been set for each grade. The grade for any given parcel of grain is based on the factor results determined during the course of an inspection.

Section 6 of the USGSA states:

> Whenever standards relating to kind, class, quality, or condition are effective . . . no person shall in any sale, offer for sale, or consignment for sale, which involves the shipment of such grain in interstate of foreign commerce . . . describe such grain as being of any grade . . . other than by an official grade designation.

In other words, the grain standards must be used to describe grain being marketed and subsequently used as the basis for all inspections.

Grain is usually inspected each time it is handled, i.e., into and out of grain elevators. As demonstrated in figure 2-4, this could result in many inspections if grain moves through each step in the marketing chain. Two separate

USDA agencies provide and/or license individuals to perform inspection services. Private companies not affiliated with either of these Government agencies also provide inspection services.

Several authorities regulate inspection requirements by specifying who will perform these services and where. In other instances, sales contracts and individual market policies dictate inspection requirements. In all cases, settlement is based on inspection requirements as required by individual sales contracts or agreements.

No single national policy exists on inspection requirements on domestic grain. Inspection can be performed by FGIS or an FGIS-licensed inspector, by a private individual licensed by USDA's Agricultural Stabilization and Conservation Service (ASCS) under the United States Warehouse Act, by private companies, or by grain elevator employees. Three main forces determine when inspection is required: warehouse licensing requirements under the Warehouse Act or individual State warehouse authorities, the Grain Trade Rules published by the National Grain and Feed Association, and the Uniform Grain Storage Agreement administered by ASCS.

Inspection of export grain is mandatory and must be provided by FGIS or an FGIS-licensed inspector. Even though inspection by FGIS is mandatory, private companies are retained in some cases by the importing country to inspect grain and represent their interests during loading.

QUALITY AS AN ISSUE

Today more competitors exist in the international grain market than just 10 years ago. In the 1970s one-third of the world supplied grain to two-thirds of the world's people. Growth in farm trade was dynamic. Today, two-thirds of the world supplies grain to the other third. Trade growth is relatively stagnant. In such a competitive atmosphere, foreign buyers have become increasingly sensitive about the quality of grain they receive.

During the debate of the Food Security Act of 1985, several Members of Congress expressed growing concern over the quality of U.S. grain exports. Accusations were made that grain elevator operators and export traders were adultering loads of grain shipped to foreign buyers; these allegations were supported by a sharp increase in foreign complaints over quality. On the other hand, traders and handlers indicated that they have been shipping grain according to specifications, and that most of the buyers' complaints were motivated by their desire to obtain a higher grade of grain at a lower price. Much of the focus of the debate concerned the adequacy of present grain standards, which were developed over 70 years ago. Critics argue that the grain standards themselves are partly to blame for customer complaints. They claim that the grain standards have not kept pace with the changing world marketplace and are frequently misunderstood by foreign buyers.

Improving U.S. grain quality—or even the perception of quality—will be much more complicated than tinkering with the criteria for determining grain grades. Grain is vulnerable to quality deterioration at virtually every stage of the production and marketing process. Many aspects of the interrelatedness of producing, harvesting, storing, handling, and testing grain need to be understood before any changes in the system can be contemplated. Understanding these relationships is the main goal of this report.

First, it is important to clarify what is meant by grain quality. Webster defines quality as an essential character; a degree of excellence; or a distinguishing attribute. In grain, such a definition has come to mean a variety of things. Quality grain could be grain free of material other than grain, or grain not cracked or spoiled, or grain with the proper characteristics for its ultimate use. Therefore no one definition of quality applies as it relates to grain.

For the purpose of this assessment, grain quality will be defined in terms of sanitary, physical, and intrinsic characteristics.

- *Sanitary quality* characteristics refer to the cleanliness of the grain. They include the presence of material other than grain, dust, broken kernels, rodent excreta, insects, residues, fungal infection, and other nonmillable materials. They are essentially characteristics that detract from the overall value and appearance of the grain.
- *Physical quality* characteristics are associated with the outward visible appearance of the kernal or measurement of the kernel. These characteristics could include kernel size, shape, and color; kernel moisture; kernel damage; and kernel density.
- *Intrinsic quality* characteristics are critical to the specific use of the grain and can only be determined by analytical tests. In wheat, for example, such characteristics refer to protein, ash, and gluten content. For corn they could include starch, protein, and oil content, and for soybeans, protein and oil content. These characteristics, along with the specific values, will differ, depending on the grain and its final use.

Using these grain quality definitions, the following chapters will consider various aspects of the quality issue. Chapters 3 through 5 look at which quality attributes are considered important by buyers of U.S. grain and how views on what is important change. Chapters 6 through 10 analyze the U.S. grain system's ability to produce and deliver quality grain, and compares the system with that of other major grain exporters. Chapter 11 identifies policy options to enhance the quality of U.S. grain.

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Chapter 3

Basic Grain Processing Industries

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Chapter 3

Basic Grain Processing Industries

Wheat, corn, and soybeans can be used in a variety of ways. They can be used directly in food for human consumption, as in the case of wheat flour and soybean oil. Products from these grains can also be mixed with other ingredients, as is the case with corn starch and corn sugars, to produce a multitude of products for human consumption. Wheat and corn are fed directly to animals or mixed with other ingredients to produce balanced diets. Meal produced during soybean oil extraction is used as a feed supplement to increase the protein content of mixed feed. Byproducts from the various processes, such as millfeed produced from wheat milling and steep-water concentrates from corn wet milling, are used by the feed industry or for industrial use. In addition, new uses for these grains are constantly being developed—for example, ethanol and biodegradable plastics produced from corn. Therefore, the physical and intrinsic characteristics required of each grain vary; more important, they must be assessed in terms of their various commercial uses.

The basic uses for wheat, corn, and soybeans in the United States are very similar to those in countries that import these grains. The basic processes used to produce wheat flour, corn starch, soybean oil, and so on are similar everywhere. Yet, differences in processing technologies exist, as do cultural preferences for certain types of products. The specific physical and intrinsic attributes required of finished products for U.S. consumption may therefore differ from those required for a specific product in an importing country, even though the basic processing technology is similar.

When identifying the basic sanitary, physical, and intrinsic requirements for wheat, corn, and soybeans, it is important that the technology involved with producing the intermediate product and the quality required of the finished product be understood. This chapter thus provides basic information on grain processing industries and technologies.

GRAIN PROCESSING INDUSTRIES

Three basic industries—milling (wheat and corn), feed manufacturing, and soybean processing—process wheat, corn, and soybeans.

Milling Industries

Milling is a process by which kernel components are separated physically or chemically. Each milling process yields products indicative of the grain being milled. Wheat is milled to produce various types of flour. In the case of corn, dry or wet processes are used, and each results in different products and byproducts.

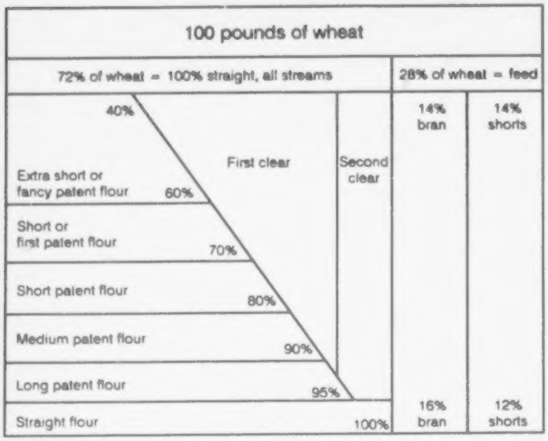
The many products of milling can be used directly as food or as ingredients in another type of food product. Specialty uses of milling products have also been developed, along with uses for the various byproducts. Thus each milling process entails almost complete utilization of all the grain.

Wheat Milling

Wheat is milled to remove the bran and germ and reduce the wheat kernel to flour to be used in various baked and nonbaked goods. Other products of the process, e.g., vital gluten, can supplement other edible products. Millfeed, the material remaining after all the usable flour is extracted, is used by the feed industry either directly or as a feed supplement.

In general, 100 pounds of wheat will produce 72 pounds of flour. The remaining 28 pounds is classified as millfeed (figure 3-1). In large flour mills, 30 or more flour streams of varying com-

Figure 3-1.—Flour Grades Obtained in the Process of Milling



SOURCE: Wheat Flour Institute, "From Wheat to Flour," revised ed., Washington, DC, 1981

position and purity may be collected, grouped, and merchandised. Combining all the streams results in a straight grade flour. The more highly refined flour streams are taken off separately and sold as patent grade flours. The remaining streams contain more bran and germ and are considered clear flour. Raising the proportion of this that is included in the patent flour lowers the quality of the remaining clear flour (8).

Flour is used in a variety of U.S. products. Fancy patent flour from soft wheats is used in cake products. In the case of hard wheats, short patent is used in premium breads, standard patent in featured breads, medium and long patent and straight in bread and rolls, and high gluten flour in hearth breads and Kaiser rolls. Flour types and grades produced in non-U.S. mills vary by mill and by the type of flour product.

The Association of American Feed Control Officials has defined eight different types of millfeeds: wheat bran, wheat feed flour, wheat germ meal, wheat mill run, wheat middlings, wheat shorts, wheat red dog, and defatted wheat germ meal (9). These products are used to feed cattle, poultry, and other small animals as part of a formulated ration.

In 1988, a total of 211 flour mills and 18 Durum mills were operating in the United States (5). The basic flour types produced and the daily production capacities from these mills are hard wheat flour (843,606 cwt), soft wheat flour (247,931 cwt), whole wheat flour (40,205 cwt), and Durum flour (96,540 cwt). Table 3-1 provides a breakdown of the 211 hard, soft, and whole wheat flour mills by size and capacity. Twenty-four percent of mills in the United States produce 84 percent of all flour.

Dry Milling Corn

The dry milling process requires the miller to remove the corn hull and germ without reducing the endosperm. The dry milling and alkaline cooking industries processed about 161 million bushels of corn in 1986. Total corn usage has ranged from a low of 154 million bushels in 1975 to a high of 170 million bushels in 1982 (table 3-2).

This process produces flaking grits, meals, flours, oil, and other products. Low-fat flaking grits are the highest valued grit product and are used primarily in breakfast foods. General food use accounted for 1,125 million pounds of dry milling product in 1977, with breakfast cereals using the most (table 3-3).

Table 3-4 shows the yield of primary and alternate products produced by dry milling. Breakfast cereal is produced from large flaking grits. Coarse and regular grits are used by the brewing industry, while corn meal is made from material too small to make grits. Corn meal and flour are made from finely ground starchy endosperm and used in various baked goods, snack foods, and mixes, but they also have in-

Table 3-1.—Active Wheat Flour Capacity by Size Group (wheat, soft wheat and whole wheat flour)

Hundredweights per day	Number of mills	Active capacity	Inactive capacity
Under 200	21	2,371	—
200-399	22	6,415	—
400-999	17	10,330	—
1,000-4,999	61	168,670	—
5,000-9,999	48	317,200	—
10,000 & over	42	615,750	—
Total	211	1,120,736	—

SOURCE: *Milling and Baking News*, "1988 Milling Directory/Buyers Guide" (Merriam, KS: Sosland Publishing Co., 1988).

Table 3-2.—Amount of Corn Used Annually for Dry Milled and Alkaline Cooked Products in the United States

Year[a]	Dry-milled and alkaline cooked products (million bushels)	Total U.S. corn production (million bushels)	Dry-mill share (in percent)
1975 . . .	154	5,841	2.6
1976 . . .	155	6,289	2.5
1977 . . .	158	6,505	2.4
1978 . . .	155	7,268	2.1
1979 . . .	158	7,928	2.0
1980 . . .	160	6,639	2.4
1981 . . .	162	8,119	2.0
1982 . . .	170	8,235	2.1
1983 . . .	164	4,175	3.9
1984 . . .	160	7,674	2.1
1985 . . .	161	8,865	1.8
1986 . . .	161	8,253	2.0

[a] Year begins Sept. 1.

SOURCE: U.S. Department of Agriculture (USDA), Economic Research Service, "Feed Situation and Outlook Report," FdS-302, Washington, DC, May 1987; USDA, *Agricultural Statistics, 1986* (Washington, DC: U.S. Government Printing Office, 1986).

Table 3-3.—Estimated Dry Milling Product Quantities Classified According to End Use, 1977

Use	Quantity (million lbs)	
Brewing		1,850
Food, general		1,125
Breakfast cereals	800	
Mixes (pancake, cookie, muffins, etc.)	100	
Baking	50	
Snack foods	100	
Breadings, batters, baby foods, etc.	75	
Fortified Public Law 480 foods		485
Nonfood		530
Gypsum board	100	
Particle, fiber board, plywood	40	
Pharmaceuticals, fermentation	200	
Foundry binders	90	
Charcoal binders	75	
Other (paper, corrugating, oil well drilling fluids	25	
Animal feed		2,200
Total		6,190

SOURCE: R.J. Alexander, "Corn Dry Milling: Processes, Products and Applications," *Corn Chemistry and Technology*, S.A. Watson and P.E. Ramstad (eds.) (St. Paul, MN: American Association of Cereal Chemists, 1987).

Table 3-4.—Typical Proportion of Corn Products From a Degerming Dry Mill (percent)

Product	Yield
Flaking grits	12
Coarse grits	15
Regular grits	23
Coarse meal	3
Dusted meal	3
Flour	4
Oil	1
Hominy feed	35
Shrinkage	4

SOURCE: O.L. Brekke, "Corn Dry Milling Industry," *Corn: Culture, Processing, Products*, G.E. Inglett (ed.) (Westport, CT: AVI Publishing Co., Inc., 1970).

dustrial uses. Corn oil obtained from dry milling is used in food products and in industrial uses. Hominy feed consists of all the byproducts such as hull fractions, unseparable mixtures of hull, endosperm, germ, germ meal, and corn cleanings. It is the single largest product sold by dry millers (6).

The number of corn dry mills in the United States has dropped from 152 in 1965 to only 68 in 1986. Of these, 55 had daily capacities of under 12,000 bushels, 8 could handle between 12,000 and 36,000 bushels, and 5 could process 36,000 bushels a day (4). The majority of corn dry mills are located in the midwestern and southeastern part of the United States. The 13 largest mills have a combined estimated daily capacity of 445,000 bushels, about 69 percent of the total corn usage for dry milling.

Wet Milling Corn

The amount of corn processed by the wet milling industry has increased from 155 million bushels in 1960 to 645 million bushels in 1985, accounting for some 12 percent of domestic corn use (3).

Wet milling corn produces starch, oil, and sweeteners (table 3-5). Corn starch is used in food and nonfood products by the brewing and baking industries; in the production of chemicals, drugs, and pharmaceuticals; by the paper industries; and in the production of ethanol. Sweeteners are used by the baking, beverage, canning, and feed industries. Byproducts from the wet milling process, including the water used to steep the corn prior to milling, are used by the feed industry.

Feed Manufacturing

Livestock and poultry consumed 85 percent of domestic corn during the 1980s. Over the past 5 years, swine consumed 34 percent of the corn; beef, 22.3 percent; dairy, 18.2 percent; poultry, 21.3 percent; and other classes of animals, 5.1 percent. Wheat use in feed, on the other hand, is significantly lower. In 1985 wheat

Table 3-5.—Shipment of Products of the Corn Refining Industry in the United States, 1983-85 (thousand pounds)

Product	1983	1984	1985
Starch products (includes corn starch, modified starch, and dextrin)	4,018,905	4,182,866	4,225,171
Refinery products (includes glucose syrup, high-fructose corn syrup dextrose, corn syrup solids, and maltodextrins)	16,005,529	17,921,126	20,341,535
High-fructose corn syrup	9,707,041	11,502,324	13,920,406
Other products:			
Corn oil crude	72,612	116,142	164,382
Corn oil refined	399,919	407,456	382,234
Corn gluten feed	7,391,069	8,739,730	8,811,476
Corn gluten meal:			
41% protein	19,115	20,272	18,503
60% protein	1,383,129	1,635,228	1,609,112
Corn oil meal	28,728	29,465	48,585
Steepwater	211,937	300,770	282,333
Hydrol	208,807	216,558	228,742
Ethanol (thousand gallons, 100%)	325,000	375,000	425,000

SOURCE: Stanley A. Watson and Paul E. Ramstad (eds.), *Corn Chemistry and Technology* (St. Paul, MN: American Association of Cereal Chemists, 1987).

and rye combined accounted for 16.9 percent of total feed grain consumption by livestock.

Wheat and corn can be ground and fed to animals or ground and mixed with other ingredients to produce a balanced diet for a particular species. Each animal species has specific dietary requirements; when corn and wheat are used, ingredients must be added to overcome certain deficiencies in these grains (7). Feed concentrates, byproducts from wheat and corn milling processes, soybean meal, animal protein, and other byproducts are mixed with other feeds or fed directly to livestock.

The modern feed manufacturer blends ingredients using a computer program designed to select the lowest priced ingredient that is a significant source of the desired nutrients. For most nutrients, published average values are used and any deviation from these values will render the feed deficient and affect animal performance.

Soybean Processing

Soybean processing separates oil by solvent-extraction from the nonoil portion of the bean. The soybeans are cleaned prior to being cracked, hulls are removed, and the cracked dehulled pieces are heated and rolled into flakes. Crude oil is then extracted from the flakes. After extracting the oil, the flakes can be toasted and ground into meal products.

The two major products from soybean processing are high-protein meal and oil. Food uses of oil include shortening, margarine, and cooking and salad oils; nonfood uses include paint, varnish, resins, and plastics. Soybean meal, which is the largest product produced from this process, is used by the feed industry as a protein supplement in manufactured feeds.

BASIC PROCESSES USED TO PRODUCE GRAIN PRODUCTS

To fully understand the quality requirements of each industry, a general knowledge of the basic technologies used to process the various grains is important. Since such technologies are similar worldwide, general descriptions are provided in this section. Modifications of and improvements to these will vary by individual company within the United States and among countries around the world.

Dry Milling Wheat and Corn

The basic process used to mill wheat and corn involves cleaning, conditioning, grinding, and sifting. In the case of dry milling corn, degerming also takes place.

Samples are taken from each incoming shipment of wheat and corn and tested. The characteristics of the wheat determine how it will be handled, since different types are usually blended before milling to meet various flour requirements. Figure 3-2 provides a simplified wheat milling flowchart, and figure 3-3 is a dry corn milling flowchart. The sequence, number, and complexity of different operations will vary somewhat between mills.

The first step in milling involves cleaning the grain to remove weed seeds, other grains, and material such as sticks, stones, dirt, and other debris. This involves the use of scalpers to remove large material, aspiration to remove fine material, and screens. Magnetic separators can also be used to remove any metal from the grain.

Disc separators are used to catch individual kernels and reject larger or smaller ones, thus creating a uniform kernel size for milling. In the case of wheat, the grain passes through a scourer that throws the kernels against a surface, buffing each one and breaking off the beard. Air currents remove the dust and loosened particles of the bran coat.

Wheat and corn are conditioned prior to milling. This process, called tempering, involves adding moisture. Tempering is done to aid in removing the bran from the endosperm during grinding, since the outer bran layers are brittle and must be toughened. Wheat is held in tempering bins for usually 8 to 24 hours, depending on the type of wheat. The percent of moisture added, the amount of soaking time, and the temperature differ for soft, medium, and hard wheats. Corn is injected with steam or sprayed with warm water in a tempering chamber. This may occur in one to three stages before the corn finally reaches 18- to 24-percent moisture. The moist corn is then held in the tempering bin for up to 6 hours. Corn moisture, holding time, and the temperature during conditioning are critical for obtaining correct moisture gradients in the kernel.

Wheat Milling Process

After tempering, wheat is moved to an entoleter, which consists of discs revolving at high speed that crack unsound wheat kernels and separate them from the grain stream. Wheat flows from the entoleter to the grinding bin, where it is held and metered into the mill itself.

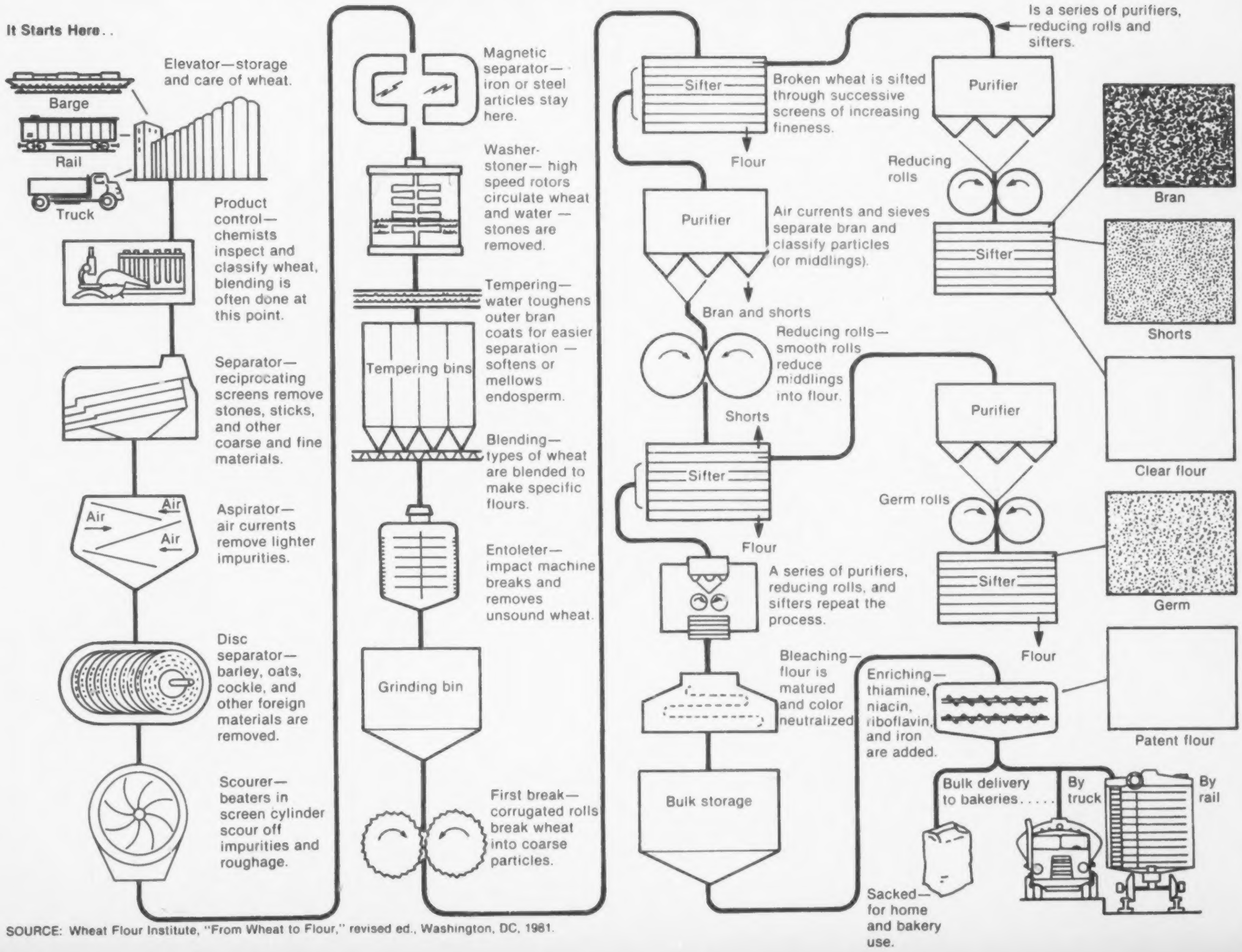
Corrugated rolls are used to break the wheat into coarse particles. The initial set of these (referred to as the "first break" rolls) break the kernel into very coarse pieces. These rolls can be adjusted for spacing as well as speed to achieve the exact milling surface desired, depending on the type of wheat and its condition. As many as four to six break rolls, with successively smoother surfaces, can be used to further reduce the kernel into flour.

The coarse pieces of wheat and bran produced from the first break are sifted over a series of bolting cloths or screens to separate larger from smaller particles. Sifters consist of as many as 27 frames of bolting cloth with meshes that grow progressively smaller from top to bottom. Larger material is shaken off at each step and the finer flour sifts to the bottom. The coarse pieces are sized and carried to the second set of break rolls. The second break rolls are spaced closer together, producing a finer material. This material is then sent to a sifter and the process repeats itself.

Flour is obtained from each break roll and sifting operation. However, fragments of endosperm, bran, and germs called middlings remain after each sifting. These are sent to purifiers, where air removes bran particles and bolting cloth is again used to separate coarser fractions by size and quality. The coarse material is then sent to reduction rolls and again sifted (8).

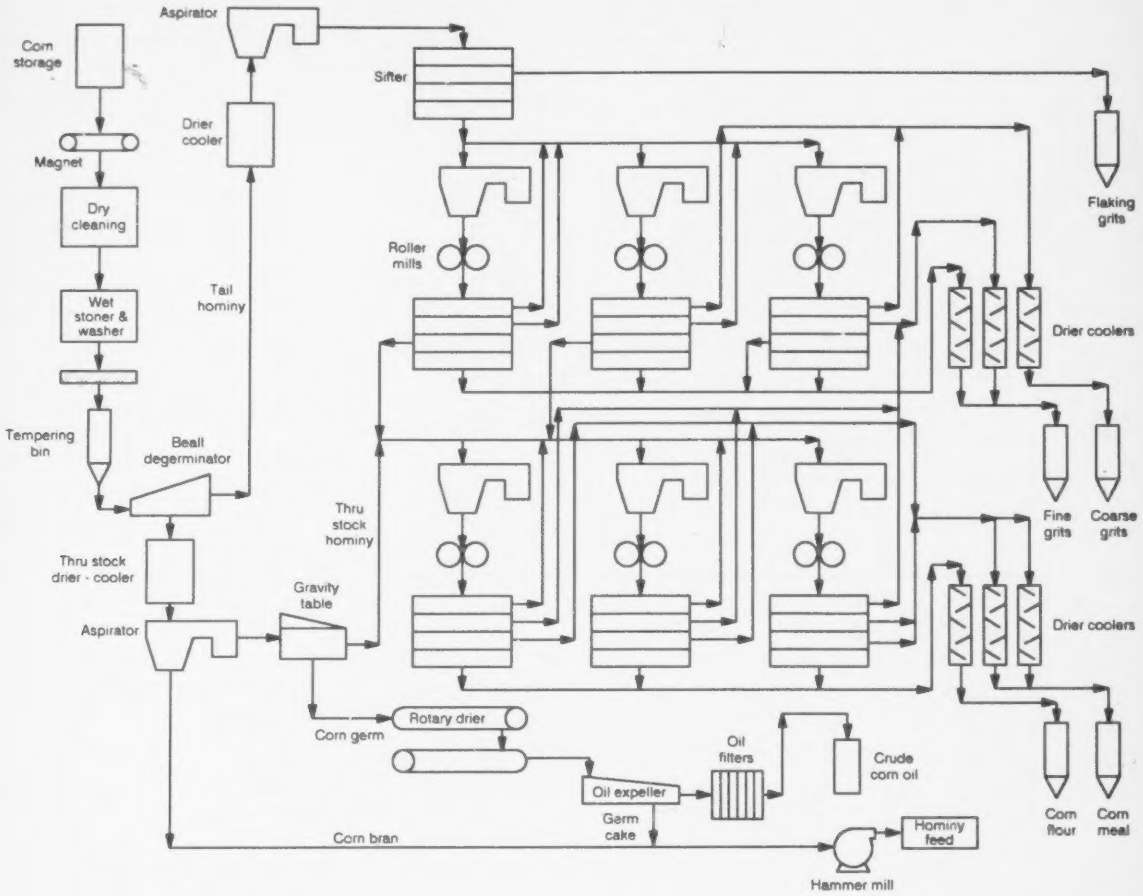
The process of grinding, sifting, purifying, and reducing is repeated many times until the maximum amount of flour is obtained. Each process results in a separate flour stream. For example, flour is produced from each break and middlings reduction (first, second, third, etc.).

Figure 3-2.—How Flour is Milled (a simplified diagram)


It Starts Here . .
Barge
Rail
Truck
Elevator—storage and care of wheat.
Product control—chemists inspect and classify wheat, blending is often done at this point.
Separator—reciprocating screens remove stones, sticks, and other coarse and fine materials.
Aspirator—air currents remove lighter impurities.
Air
Air
Air
Disc separator—barley, oats, cockle, and other foreign materials are removed.
Scourer—beaters in screen cylinder scour off impurities and roughage.
Magnetic separator—iron or steel articles stay here.
Washer-stoner—high speed rotors circulate wheat and water — stones are removed.
Tempering—water toughens outer bran coats for easier separation — softens or mellows endosperm.
Tempering bins
Blending—types of wheat are blended to make specific flours.
Entoleter—impact machine breaks and removes unsound wheat.
Grinding bin
First break—corrugated rolls break wheat into coarse particles.
Sifter
Broken wheat is sifted through successive screens of increasing fineness.
Flour
Purifier
Air currents and sieves separate bran and classify particles (or middlings).
Bran and shorts
Reducing rolls—smooth rolls reduce middlings into flour.
Shorts
Sifter
Flour
A series of purifiers, reducing rolls, and sifters repeat the process.
Bleaching—flour is matured and color neutralized
Bulk storage
Is a series of purifiers, reducing rolls and sifters.
Purifier
Reducing rolls
Sifter
Bran
Shorts
Clear flour
Purifier
Germ rolls
Sifter
Germ
Flour
Enriching—thiamine, niacin, riboflavin, and iron are added.
Patent flour
Bulk delivery to bakeries. . . . .
By truck
By rail
Sacked—for home and bakery use.

SOURCE: Wheat Flour Institute, "From Wheat to Flour," revised ed., Washington, DC, 1981.

Figure 3-3. – Production Flow Chart for a Typical Corn Tempering-Degerming System


Aspirator
Corn storage
Magnet
Dry cleaning
Wet stoner & washer
Tempering bin
Drier cooler
Tail hominy
Beall degerminator
Thru stock drier - cooler
Aspirator
Gravity table
Thru stock hominy
Sifter
Roller mills
Flaking grits
Drier coolers
Fine grits
Coarse grits
Drier coolers
Corn flour
Corn meal
Rotary drier
Corn germ
Oil filters
Crude corn oil
Oil expeller
Germ cake
Corn bran
Hominy feed
Hammer mill

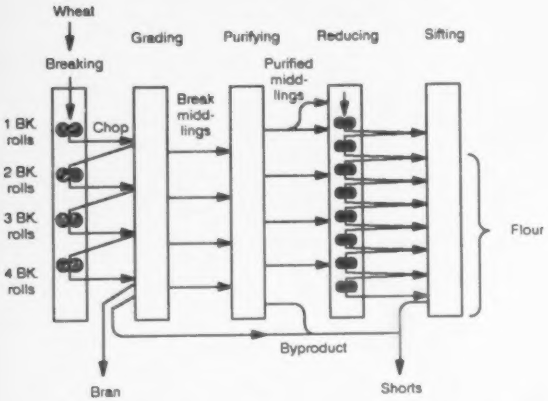
SOURCE: Richard J. Alexander, "Corn Dry Milling: Processes, Products, and Applications" in *Corn Chemistry and Technology* (St. Paul, MN: American Association of Cereal Chemists, 1987)

Figure 3-4 shows an example of a milling process with four breaks. In this case, 12 different flours are produced—four from each break and eight from each reduction (2).

Flour from each point in the process has different characteristics and baking properties and can be combined in many different ways. Flour from the first few middlings separations is the most highly refined. After each additional process the flour contains more bran and germ. In large mills, there can be 30 or more separate streams.

Some mills, in addition to producing flour, produce vital wheat gluten, essentially a powdery product containing 75 to 80 percent protein with a bland flavor that is able to absorb water 2.5 times its dry weight. This product is relatively simple to produce in that flour is washed with water and then dried. Vital wheat gluten is used as a supplemental ingredient in

Figure 3-4.—Block Flow Sheet



SOURCE: Canadian International Grains Institute, "Grain & Oil Seeds, Handling, Marketing, Processing," 3rd ed., revised, Winnipeg, MB, Canada, 1982

breadmaking especially by commercial bakers. It is added to a dough that requires additional protein to develop properly.

Corn Dry Milling Process

Degermination is the process by which the corn kernel is broken apart into endosperm, germ, and pericarps (6). Although a few companies use impact mills or granulators, about 90 percent of the dry mills producing flaking grits use the Beall degermer almost exclusively. This is a cone-shaped mill with rows of small conical protrusions that rotate within an outer conical surface that also has protrusions. This process causes corn-on-corn rubbing to remove germs, pericarps, fines, and a few small grits called through-stock. Tail-stock consists primarily of grits that are free of attached germs and pericarps.

After degerming, through-stock is normally wetter than the tail-stock and must be dried. This is accomplished by rotary steam-tube dryers that quickly heat the products to 140 to 160 °F. After drying, the stock is cooled to 90 to 100 °F.

Tail-stocks consisting of large pieces of endosperm are aspirated to remove loose pericarps. The material is then sieved. Material passing through a 3.5 mesh/inch sieve but not a 5 mesh/inch sieve is considered large flaking grits. Material that will not pass through the 3.5 mesh/inch sieve is recycled for retempering and degermination. Whatever passed through the 5 mesh/inch sieve is then sieved using 6 and 10 mesh/inch sieves. Anything passing through the 6 but not the 10 mesh/inch sieve is considered brewers and coarse grits. If there are any attached germs or pericarps, the material will be roller-milled.

Several sets of corrugated rollers are used in a manner similar to that described in the wheat milling section. Smaller numbers of corrugations are used for the first break to produce coarse grits. Second and third break rolls use more corrugations, resulting in more finely ground products. After grinding, the material is sifted and then aspirated to remove free pericarps.

Through-stock containing germs is aspirated to remove loose pericarps and then sent to gravity tables for separation. The germ fractions can then be dried and sent to an oil expeller or solvent oil extraction process to recover the crude oil. The germ meal remaining after the crude oil has been extracted is used in hominy feed. The material other than the germ separated with the gravity table is recycled back to the first break rolls to be processed with the tail-stock.

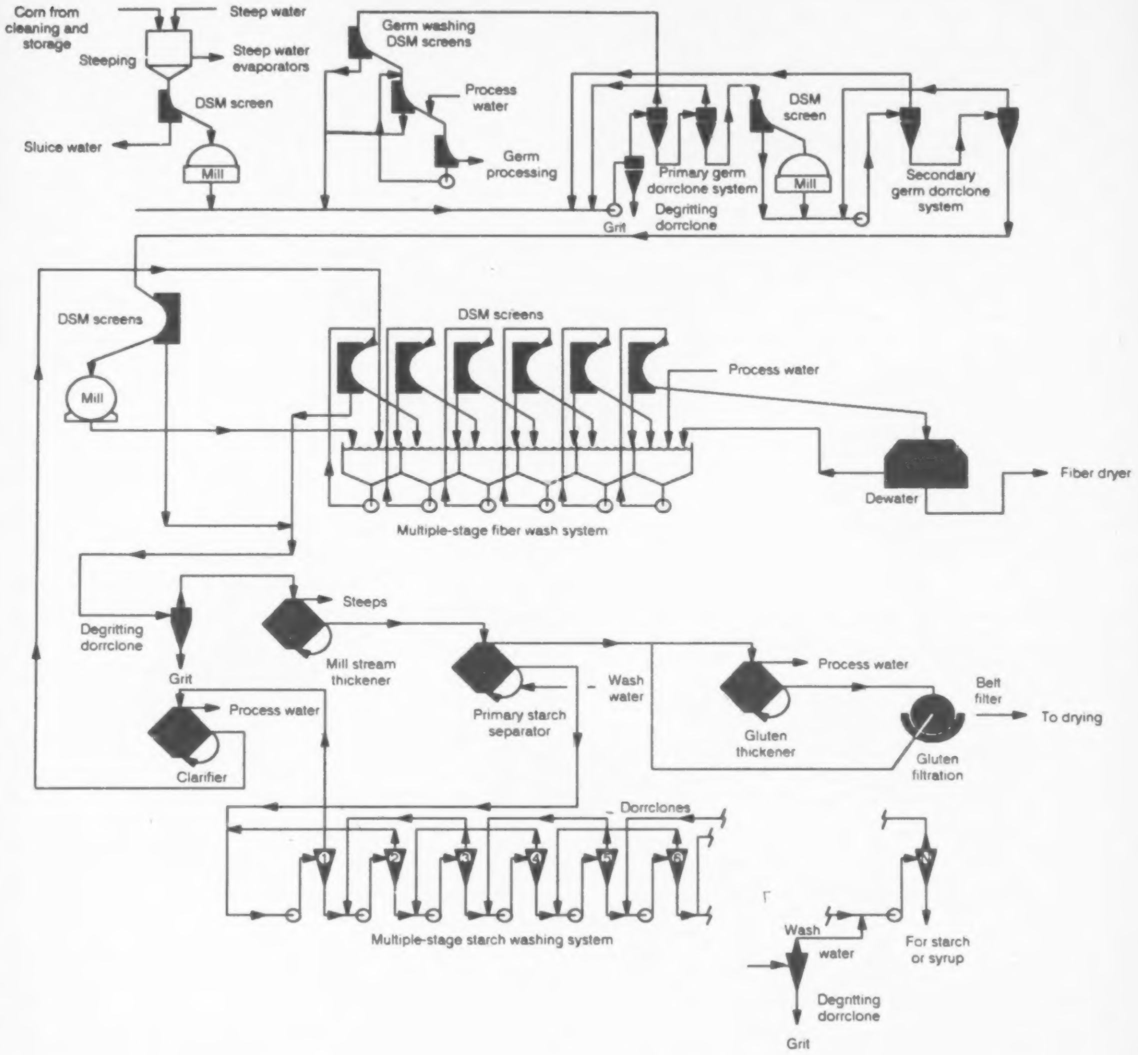
Wet Milling Corn

Corn is first cleaned by screening and aspiration to remove dust, chaff, cobs, stones, and so on, similar to the processes described for dry milling (figure 3-5). After cleaning, the corn is moved on to the refining process (3).

As in dry milling, corn must be tempered. This is accomplished by placing the grain in steeping tanks and adding water containing sulfurous acid that has been heated to 125 °F. Corn is held in steeping tanks for 22 to 50 hours. During this time the water is recirculated and reheated.

Water is used to transport the corn from the steeping tanks to holding bins. It is screened off prior to the wet corn being placed in the

Figure 3-5.—Wet-Milling Process Flow Diagram (showing equipment arrangement for the separation of the major components—steepwater, germ, fiber, gluten, and cornstarch)

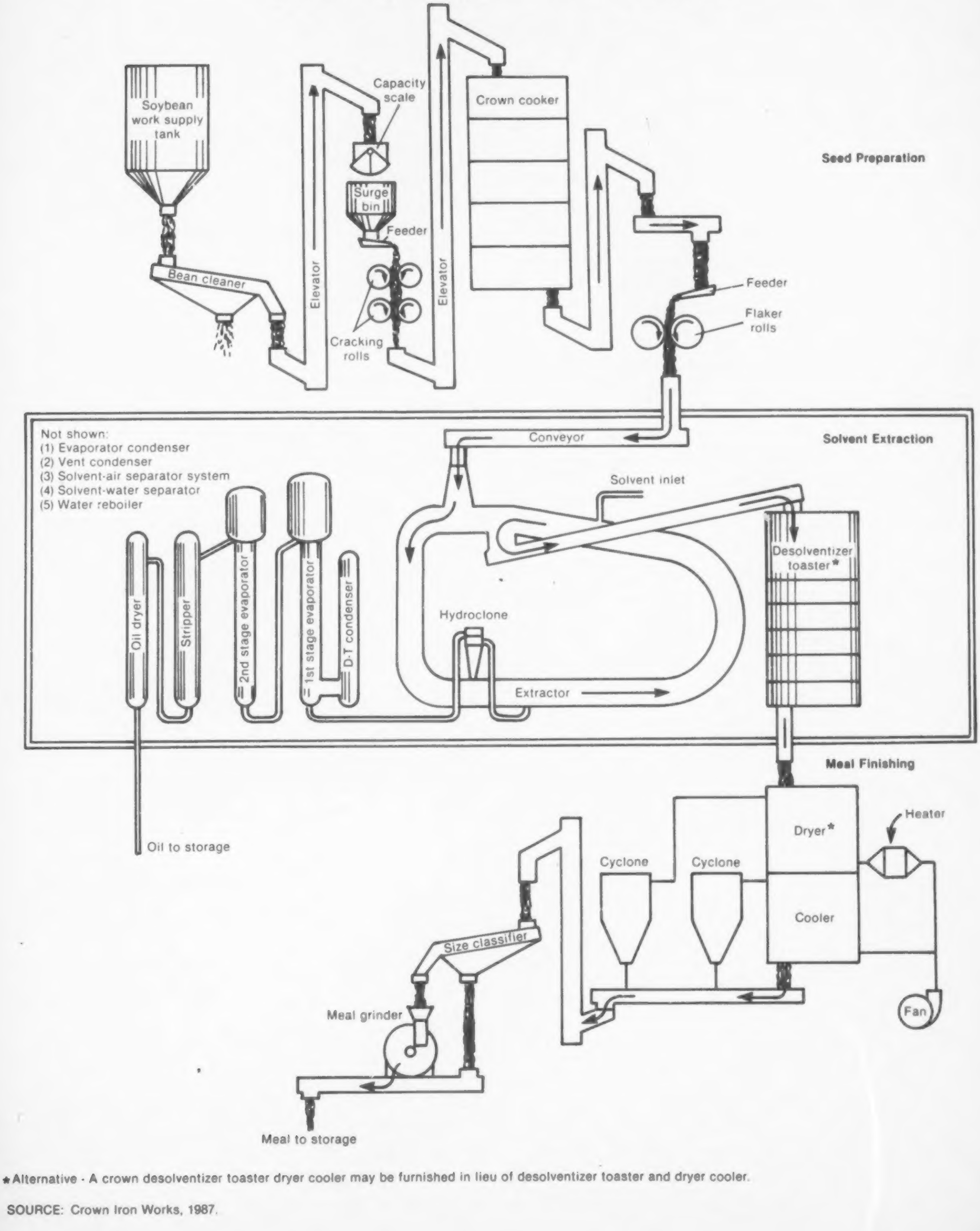

Corn from cleaning and storage
Steep water
Steeping
Steep water evaporators
DSM screen
Sluice water
Mill
Germ washing DSM screens
Process water
Germ processing
DSM screen
Primary germ dorrclone system
Degritting dorrclone
Grit
Mill
Secondary germ dorrclone system
DSM screens
Mill
DSM screens
Process water
Dewater
Fiber dryer
Multiple-stage fiber wash system
Steeps
Degritting dorrclone
Mill stream thickener
Grit
Process water
Clarifier
Primary starch separator
Wash water
Process water
Gluten thickener
Belt filter
To drying
Gluten filtration
Dorrclones
1
2
3
4
5
6
N
Multiple-stage starch washing system
Wash water
For starch or syrup
Degritting dorrclone
Grit

SOURCE: James B. Mag, "Wet Milling: Process and Products" in *Corn Chemistry and Technology* (St. Paul, MN: American Association of Cereal Chemists, 1987).

bin. From the holding bin the corn moves into grinders that break up the kernel. Water is again added and the material is transported to flotation tanks, where the germ floats to the top. The germs are recovered, washed, and screened. The recovered germs are then dried and further processed to remove the oil.

The material remaining in the flotation tanks is screened to separate fiber from starch and gluten. About 30 to 40 percent of all the starch is separated at this stage. The remaining material is further processed, washed, and screened to separate more starch and gluten. Starch is purified by washing and can be dried, treated

Figure 3-6.—Typical Soybean Extraction Process Flow


Soybean work supply tank
Capacity scale
Surge bin
Feeder
Bean cleaner
Elevator
Cracking rolls
Elevator
Crown cooker
Feeder
Flaker rolls
Seed Preparation
Not shown:
(1) Evaporator condenser
(2) Vent condenser
(3) Solvent-air separator system
(4) Solvent-water separator
(5) Water reboiler
Conveyor
Solvent Extraction
Solvent inlet
Desolventizer toaster*
Oil dryer
Stripper
2nd stage evaporator
1st stage evaporator
D-T condenser
Hydroclone
Extractor
Oil to storage
Meal Finishing
Dryer*
Heater
Cyclone
Cyclone
Cooler
Size classifier
Meal grinder
Fan
Meal to storage

⭑Alternative - A crown desolventizer toaster dryer cooler may be furnished in lieu of desolventizer toaster and dryer cooler.

SOURCE: Crown Iron Works, 1987.

with chemicals to modify the starch to meet various requirements, and then processed for its various uses. The gluten is also washed and then dried, forming corn gluten meal.

Corn steepwater is processed to remove the corn solubles by evaporation. The corn solubles removed during this process are used directly by the feed industry or in the production of corn gluten feed. The corn germ meal remaining after the oil is extracted is also used in the feed industry.

Soybean Processing

Soybeans are first cleaned to remove dust, weed seeds, stones, and so on. Then they are cracked by means of corrugated rolls and moved to the dehuller (1). The hulls are drawn off between the first and second cracking rolls by dehulling equipment, using air suction (figure 3-6). Screens remove any portions of the seeds that have been removed with the hulls. Seed hulls are transported to a grinder, where they can be kept separate or recombined with the extracted meal.

The moisture content of the soybeans being processed must be between 9.5 and 10 percent. The cracked soybeans are first heated to about 140 °F and then proceed through a series of rollers, where they are flaked. Following a cooling period, the flakes are exposed to continuous extraction with hexane to reduce the oil remaining in the soybean flakes to 0.5 percent or less. The extracted flakes are then transported to dryers and held at 208 °F for approximately 10 minutes to drive off any residual hexane. From the dryer, the flakes are moved to a toaster for a 90-minute toasting at 220 °F. Then the flakes are cooled and moved to the grinder for reduction into the ultimate soybean-meal-sized product.

Crude soybean oil extracted from the meal contains impurities that can affect its quality and must be removed. The various processes used to remove objectionable impurities are designed to minimize the effect on the finished oil and the loss of oil.

CHAPTER 3 REFERENCES

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Chapter 4

Quality Attributes Important to Domestic and Overseas Industries

Grain quality, or more importantly the attributes that constitute it, is as varied as the number of grains and commercial processes used to produce finished products. Quality attributes can vary from perfect kernels used for seed to highly damaged corn kernels used in fuel production, and may entail cleanliness, health, and safety concerns. Add to this cultural differences and consumer preferences, and what may be considered high quality for one use may be considered poor quality for the next.

Other than concerns for conditions affecting sanitary quality, no one set of physical or intrinsic characteristics fully describes quality for any one particular grain. Physical and chemical differences exist between varieties as a result of heredity, soil, and climatic conditions. Further, in the case of wheat, intrinsic quality characteristics vary from one type to the next. Even in the case of flour, however, the way the flour will ultimately be used has an impact on the intrinsic wheat attributes required for high quality.

Quality attributes (sanitary, physical, and intrinsic) are measured using a multitude of specific tests designed to provide information on the various characteristics of grain. The most commonly used tests for sanitary and physical quality are those contained in the Official United States Standards for Grain. These include measurements for conditions such as kernel density; moisture; damaged, broken, or split kernels; impurities; and other visual defects. In addition to tests provided for in the grain standards, each industry, along with individual companies within each industry, has either developed or uses internationally accepted testing procedures. These determine values for intrinsic characteristics that ultimately influence decisions on the grain's suitability for a particular process and product. Even the use of any one of these tests varies by industry and is influenced by the type of product produced. Beyond tests for quality attributes, uniform or consistent quality within and between shipments can also influence buyers' perceptions of quality. The ultimate test for quality is how well the grain performs in actual use.

As processing technologies, increased numbers of uses, and more sophisticated methods of using grain become available, specialization in specific quality attributes becomes more critical. This is especially true in the case of wheat. Flour quality is more narrowly defined for milling than for baking because milling is more standardized around the world, even though it varies by level of development within a country. A multitude of baking technologies exists that are becoming more sophisticated, thus requiring flour quality to be more closely regulated. This places increased importance on the attributes required of wheat, in addition to their consistency within and between shipments.

Since what constitutes physical and intrinsic quality varies according to processor (wheat miller, corn dry and wet miller, soybean processor, and feed manufacturer), the important attributes of each were examined for this assessment. OTA identified the quality attributes important to each industry as they relate to either the attribute itself or the test used to measure the attribute. The important attributes are outlined later in this chapter. The levels at which these attributes affect the quality of a finished product are not discussed since the values placed on the attribute by an individual industry have an impact on ideal quality. For example, protein quantity and gluten strength are important attributes in wheat. However, high protein and strong gluten are required by millers to produce a high-protein, strong flour for bread, whereas low-protein and weak gluten are required for low protein, weak flour used to produce cakes and pastries. To aid further in this evaluation, surveys of domestic and overseas processors were conducted to identify the important attributes and/or tests.

SURVEY DESCRIPTION

OTA developed questionnaires for each domestic industry. The 1987 Milling Directory was used to identify wheat milling and corn dry and wet milling companies. Additional input was provided by their trade associations. Questionnaires then were sent to 119 wheat millers, 64 corn dry millers, and 6 corn wet millers—all the companies in each industry. Since there are thousands of feed manufacturers in the United States, the American Feed Manufacturers Association assisted in identifying 190 major companies to be surveyed. The Soybean Processing Directory, along with help from the National Soybean Processor Association, was used to identify 19 major soybean processing companies.

Responses were received from 57 out of 117 wheat milling companies (48 percent), 24 out of 64 corn dry milling companies (38 percent), 4 out of 6 corn wet milling companies (75 percent), 83 out of 190 feed manufacturing companies (44 percent), and 10 out of 19 soybean processing companies (53 percent).

An overseas wheat questionnaire was also developed by OTA and administered in 18 importing countries (table 4-1) by the U.S. Wheat Associates. All but one country responded. Corn and soybean overseas questionnaires were not developed since work was already being done in this area by other research groups, which provided data to OTA for use in this analysis.

In order to gather information on the importance of the specific attributes and/or tests identified, five basic areas were examined:

1. the attribute's and/or test's importance,
2. how the attribute and/or test is used when purchasing grain,
3. whether quality has decreased as evidenced by any of the tests,
4. whether grain standards adequately reflect conditions important to their operations and if more tests are needed, and
5. the test's importance as it pertains to uniformity between shipments.

Respondents were asked in several questions to rank each attribute and/or test using a scale of 1 to 7. Four was defined as being neither important nor unimportant, 5 as slightly important, 6 as moderately important, and 7 as extremely important. Yes and no questions were also used and respondents were asked to identify the attributes and/or tests of particular concern when answering yes. The information collected in this survey only represents the respondents' concerns at the time it was administered, a point worth noting given the fluctuations in perceptions about important quality issues in these industries.

Table 4-1.—Countries Included in OTA Wheat Survey, by Region

Far East	***Europe***
China	Soviet Union
Japan	Norway
Indonesia	The Netherlands
Taiwan	Italy
Republic of Korea	France
Philippines	United Kingdom
Middle East	Switzerland
Egypt	
India	
South America	
Venezuela	
Brazil	
Chile	

SOURCE: Office of Technology Assessment, 1989.

QUALITY MEASUREMENT AS EVIDENCED BY OFFICIAL STANDARDS

Official grain standards developed for wheat, corn, and soybeans establish certain factors used to describe a level of quality and provide a basis for marketing grain. (The need for grain standards and the ways they are implemented are discussed in ch. 8.) Each standard covers areas such as grain type; bulk density; degree of cleanliness; amounts of broken, shriveled, or split grains; moisture content; amounts of impurities including damaged kernels; and other areas relating to the sanitary and physical condition of grain. The levels for each factor used to define a grade, as well as their impact on the finished product, have caused considerable debate regarding the usefulness of the factors and the limits established by the grades themselves. This assessment does not address the specific limits used to define grades, but merely focuses on the factor's importance.

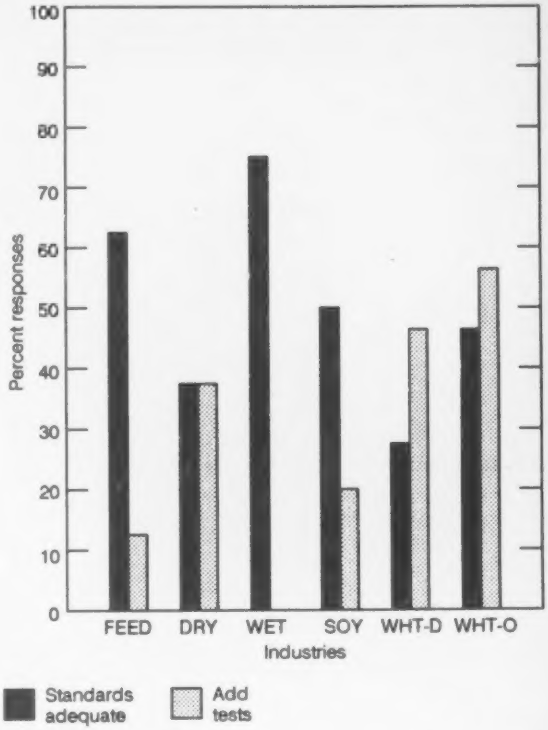
Much research has been done on determining the impact that physical properties such as type, color, kernel hardness and size, and degree of kernel damage have on various products. For example, kernel damage resulting from heating, storage and field fungi, frost, and immaturity have been shown to affect flour and oil quality. Factors such as excessive moisture content, the presence of molds or mycotoxins, the amount of material other than grain, live insects, and rodent excreta are not desired in any product.

All industries desire grain with good bulk density and safe moisture levels that is clean and free from impurities and otherwise fit for processing. These factors in various ways are covered by the grain standards. Domestic industries as well as overseas wheat millers were asked if the factors contained in the standards adequately reflect conditions important to their operation and whether additional tests are needed (figure 4-1).

For the three corn industries (wet millers, dry millers, and feed manufacturers), the degree to which the factors contained in the corn standard reflects conditions important to their operations varies; only the dry millers see a need for additional tests. Only half the domestic soybean processors considered the soybean standard adequate, but few respondents indicated the need for additional tests.

Domestic wheat millers generally felt the wheat standard does not adequately reflect conditions important to their operations. The need for additional tests is evident from responses from domestic and overseas respondents, but is slightly higher for overseas millers even though they consider the wheat standards more adequate. This section discusses each grain standard along with information gathered from the survey on the importance of the specific factors covered by each standard.

Figure 4-1.—Adequacy of Grain Standards



ABBREVIATIONS:
FEED = Feed manufacturers
DRY = Dry millers
WET = Wet millers
SOY = Soybean processors
WHT-D = Wheat millers (domestic)
WHT-O = Wheat millers (overseas)

SOURCE: Office of Technology Assessment, 1989

Wheat Standard

Wheat is grouped according to growing habit, color, and kernel texture. The major distinction, however, is its growing season. Winter wheats are planted in the fall and harvested in the summer; spring wheats are planted in the spring and harvested in the fall. Both winter and spring wheats produce grain that is red, white, or yellowish amber in color. Wheat is also grouped according to whether it is hard or soft. Spring and winter types tend to be higher in protein and are principally used in bread flour. Softer wheats, white and red types, contain lower protein and are milled into flour for cakes, cookies, pastries, and crackers. Durum wheat, which is very hard, is milled into semolina for pasta products (9). These general groupings have resulted in the establishment of seven basic classes: Hard Red Spring, Hard Red Winter, Soft Red Winter, White, Durum, Unclassed, and Mixed.

The wheat standard, in addition to establishing classes based on the above criteria using visual examination, provides information on:

- test weight,
- moisture,
- heat-damaged kernels,
- damaged kernels total,
- foreign material,
- shrunken and broken kernels,
- total defects,
- contrasting classes, and
- wheat of other classes.

Also measured are the number of live insects; the amount of dockage (material other than wheat that can be removed by scalping, aspiration, and screens); special conditions such as the presence of garlic and ergot; and the amount of stones, metal, glass, and toxic weed seeds.

Respondents were asked in the domestic survey to rank the importance of each factor as it pertains to producing four major flour types: hard wheat flour, whole wheat flour, soft wheat flour, and semolina. In addition to evaluating whether flour type has a bearing on a factor's importance, the company's daily production capacity was also factored in. The cutoff point for capacity was set at 5,600 daily hundred weight (cwt) capacity. The number of responses in the 5,600-cwt-and-over range accounted for approximately 83 percent of the total U.S. daily milling capacity.

All factors currently contained in the wheat standard were ranked as 5 (slightly important) or higher by domestic millers. Each factor's importance was similar across flour types and milling capacities, with the highest ranking being for live insects. Overseas millers also ranked all factors as 5 or higher. They were slightly less concerned than domestic millers about live insects, contrasting classes, and wheat of other classes. For the remaining factors, overseas millers generally regarded the factors as being slightly more important, especially in the case of dockage (figure 4-2).

Information was collected on whether the wheat standard is used when purchasing wheat and if contracts are based on grade only, grade and factor, or only factors (figure 4-3). Even though specific factors included in contracts vary, 79 percent of the domestic respondents indicated they use the wheat standard and include limits for one or more of the factors in their contracts. This compares with 34 percent for overseas respondents. Significant differences were found between milling capacities for domestic respondents regarding using the wheat standard for contracting. Those with 5,600 cwt and over capacity indicated that limits for some or all factors are always included in contracts.

Corn Standard

Corn is classed based on color without regard to growing habit. With color serving as the basis for classing, three classes have been established: Yellow, White, and Mixed. In addition to visually classing based on color, the corn standard provides information on:

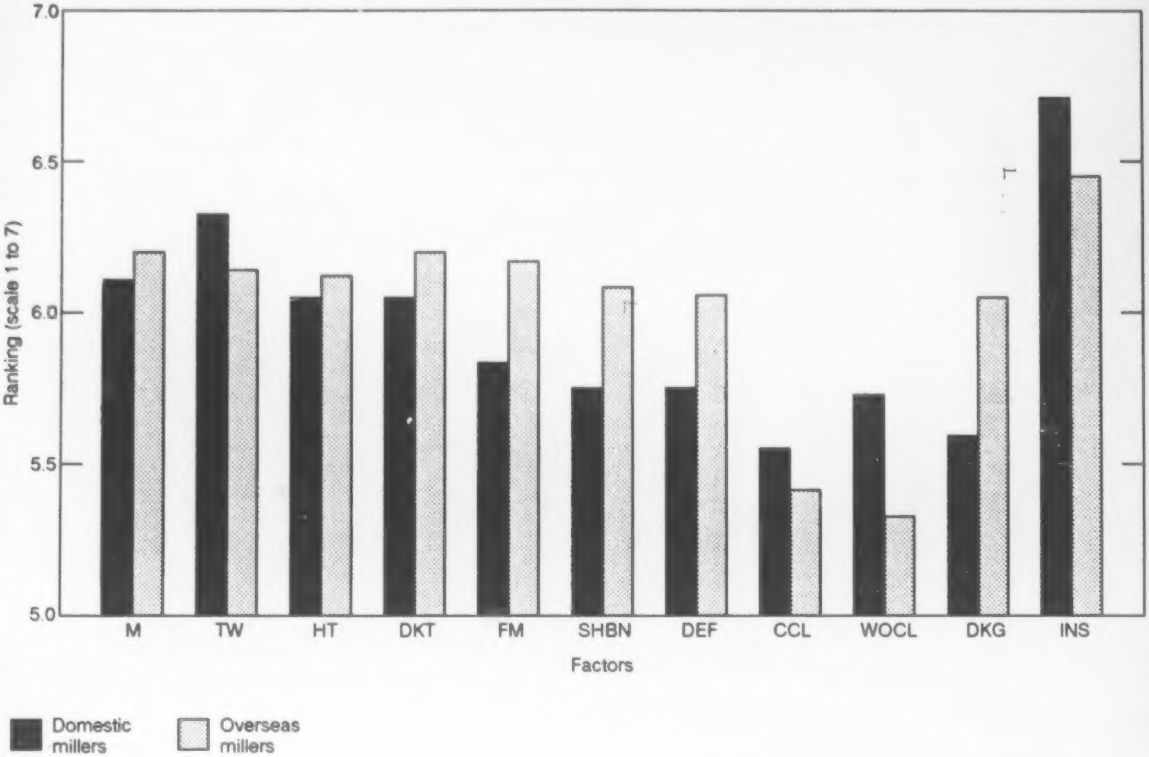
- test weight,
- moisture,
- heat-damaged kernels,
- damaged kernels total, and
- broken corn and foreign material.

The number of live insects, along with stones and toxic weeds, are also included.

Unlike the wheat standard, the corn standard is used by several different industries. Therefore, domestic questionnaires where sent to dry millers, wet millers, and feed manufacturers.

All industries ranked the factors as 5 (slightly important) or higher except for class in the wet

Figure 4-2.—Importance of Wheat Standard Factors



ABBREVIATIONS:

M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
FM = Foreign material
SHBN = Shrunken and broken kernels
DEF = Total defects
CCL = Contrasting classes
WOCL = Wheat of other classes
DKG = Dockage
INS = Live insects

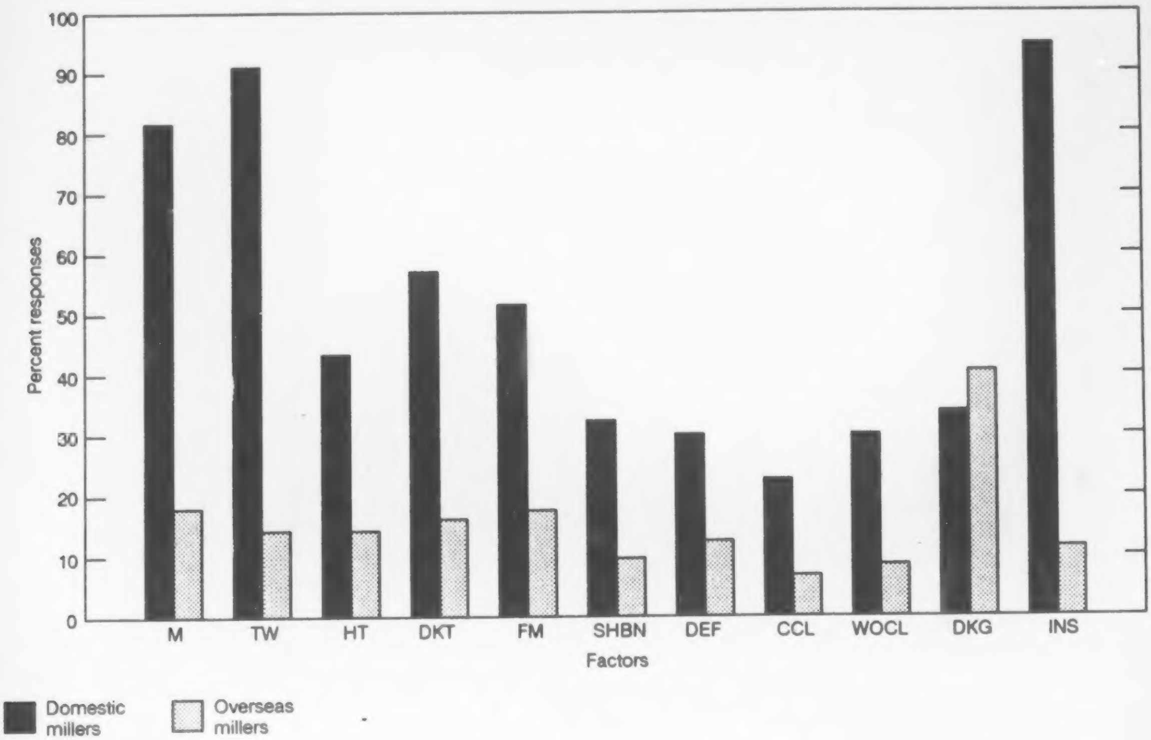
SOURCE: Office of Technology Assessment, 1989

milling and feed manufacturer responses (figure 4-4). Differences exist across all industries regarding the importance of certain factors, but wet millers consistently ranked factors as more important than the other two.

Industries differ on which factors have limits included in contracts. All wet millers indicated they use the corn standard and include limits in their contracts for one or more of the factors. This compares with 75 percent for the dry milling and feed manufacturers. Except for broken corn and foreign material, the frequency with which individual factors are included in contracts varies (figure 4-5). Moisture was mentioned the most often by feed manufacturers, whereas heat-damaged kernels was contracted for the most often by dry millers and damaged kernels total was included by wet millers.

The data on the importance to overseas industries of factors contained in the corn standard were obtained from surveys not conducted by OTA. This resulted in only one common area—contracting—between the OTA domestic questionnaire and overseas responses. Responses by the three overseas industries indicated that limits for moisture, test weight, damaged kernels total, and broken corn and foreign material are included in contracts by

Figure 4-3.—Use of Wheat Standard Factors in Contracts [a]



ABBREVIATIONS:

M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
FM = Foreign material
SHBN = Shrunken and broken kernels
DEF = Total defects
CCL = Contrasting classes
WOCL = Wheat of other classes
DKG = Dockage
INS = Live insects

[a] Percentages are based on number of responses that use standards for contracting.

SOURCE: Office of Technology Assessment, 1989

wet millers and feed manufacturers. Moisture, damaged kernels total, and live insects are included in contracts by dry millers.

Soybean Standard

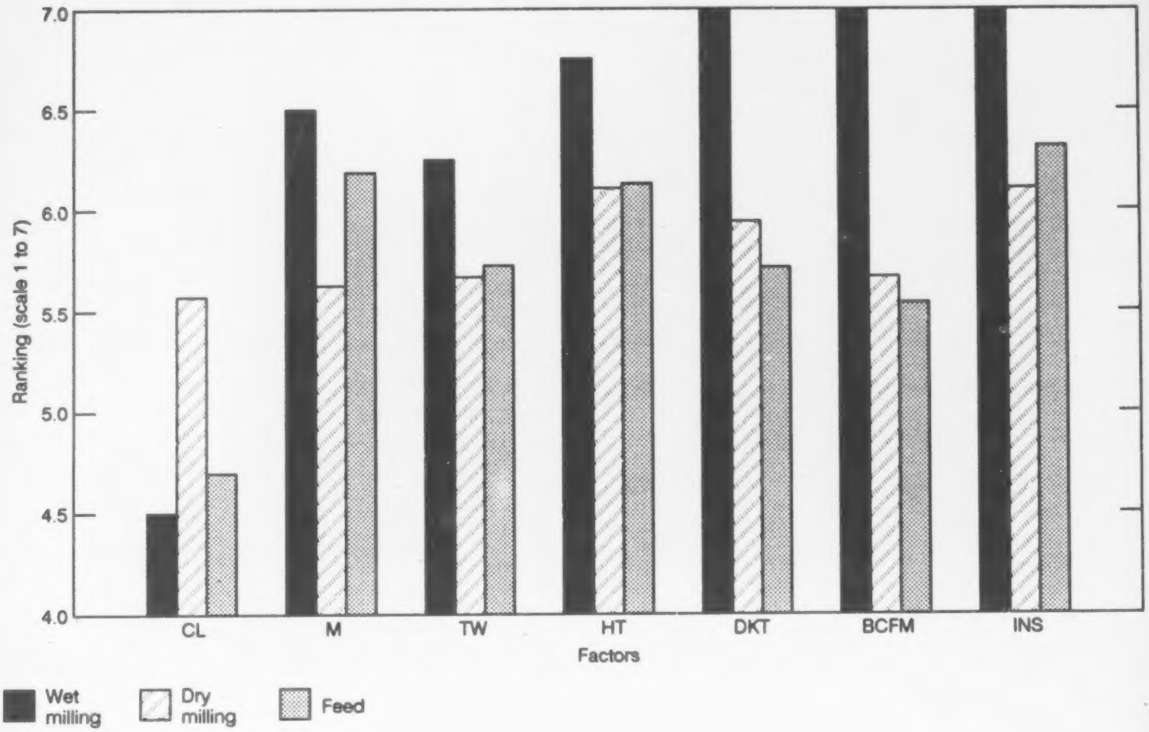
Soybeans are classed based on color, and two classes have been established: Yellow and Mixed. In addition to visually classing based on color, the soybean standard provides information on:

- test weight,
- moisture,
- heat-damaged kernels,
- damaged kernels total,
- foreign material, and
- splits.

The number of live insects, garlic, stones, and toxic weeds are also included.

Several factors were ranked below 5 (slightly important) by domestic soybean processors class, test weight, and splits (figure 4-6). The test for live insects did not rank as the most important test, as it did for wheat and corn, since live insects are not normally a problem in soybeans. Heat-damaged kernels received the highest ranking for soybeans.

Figure 4-4.—Importance of Corn Standard Factors



ABBREVIATIONS:

CL = Class
M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
BCFM = Broken corn and foreign material
INS = Live insects

SOURCE: Office of Technology Assessment, 1989.

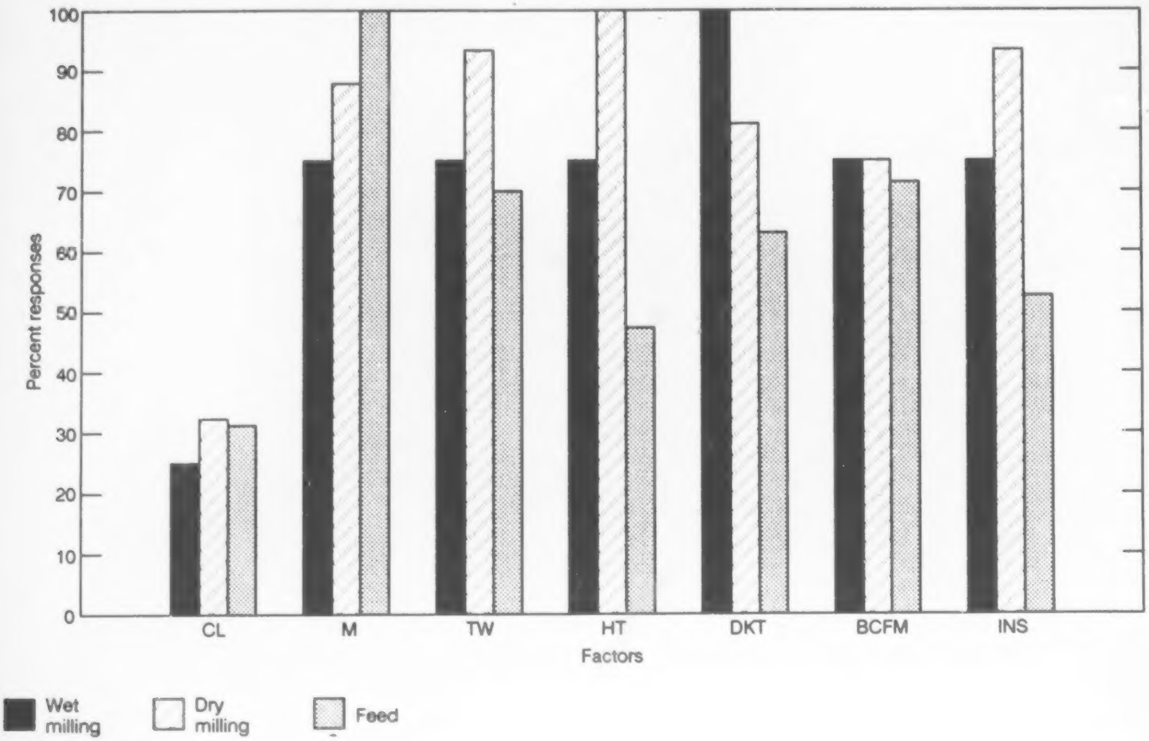
All soybean processors indicate that they use the soybean standard and set limits in their contracts for one or more factors. Moisture and heat-damaged kernels were identified as being contracted for the most often (figure 4-7).

As with the corn standard, information on the importance to importers of factors contained in the soybean standard was obtained from another survey. Moisture and foreign material were ranked as most important by overseas soybean processors, while moisture, test weight, and damaged kernels total were identified as having limits included in contracts.

IMPORTANT ATTRIBUTES FOR WHEAT, CORN, AND SOYBEANS

Many factors influence grain value and what is considered quality either by affecting wholesomeness or by affecting the yield and quality of the finished product. Factors such as pesticide residue, molds, mycotoxins, toxic weed seeds, insect fragments, and so on affect a product's wholesomeness. Yield and quality can be affected by variety; kernel size, shape, color, and hardness; foreign material, dust, and stems; and intrinsic properties such as protein, oil, and

Figure 4-5.—Use of Corn Standard Factors in Contracts [a]



ABBREVIATIONS:

CL = Class
M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
BCFM = Broken corn and foreign material
INS = Live insects

[a] Percentages are based on number of responses that use standards for contracting

SOURCE: Office of Technology Assessment, 1989

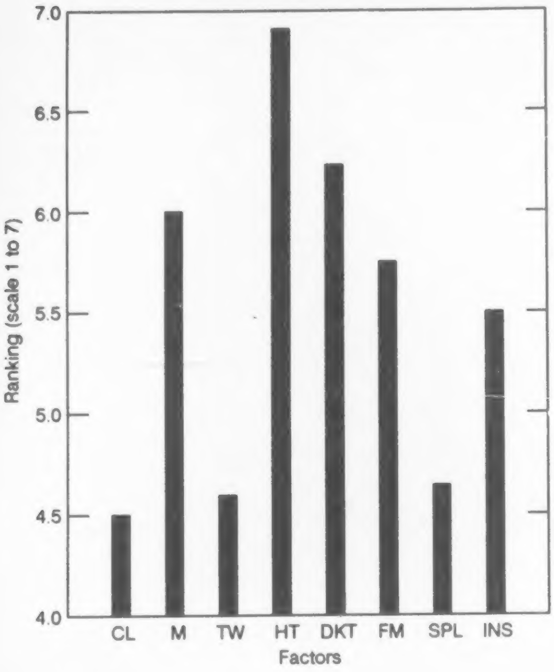
starch. This section examines wheat, corn, and soybeans for these type of factors.

Wheat

The ultimate test for wheat quality is whether it will bake an acceptable product. Protein quantity and quality, the amount of alpha amylase, and dough handling properties (water absorption, mixing time, and extensibility) along with other tests are used as indicators of quality and impact on baking quality. Except for Durum, the differences between the amount of protein required to produce certain products and the range of protein between classes reveal the inability of any one wheat class to be perfectly suited for any one finished product (figure 4-8). This is also true for wheats produced in various regions of the world. This forces millers to blend different wheat types in order to produce the flour quality desired. Not only can different types be blended, but importers blend different U.S. wheat classes with wheats imported from other countries (table 4-2).

Millers blend wheats in order to produce flour that can meet the variety of demands of various finished products. In many instances flour produced from the various flour streams

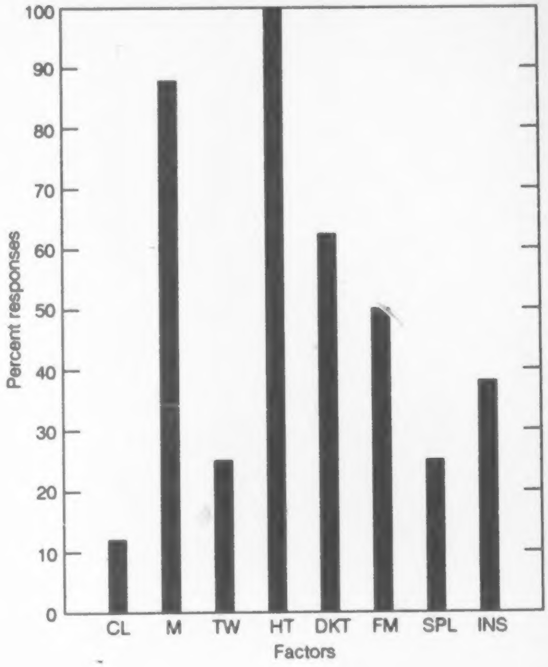
Figure 4-6.—Importance of Soybean Standard Factors



ABBREVIATIONS:
CL = Class
M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
FM = Foreign material
SPL = Splits
INS = Live insects

SOURCE: Office of Technology Assessment, 1989

Figure 4-7.—Use of Soybean Standard Factors in Contracts[a]



ABBREVIATIONS:
CL = Class
M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
FM = Foreign material
SPL = Splits
INS = Live insects

[a] Percentages are based on number of responses that use standards for contracting

SOURCE: Office of Technology Assessment, 1989

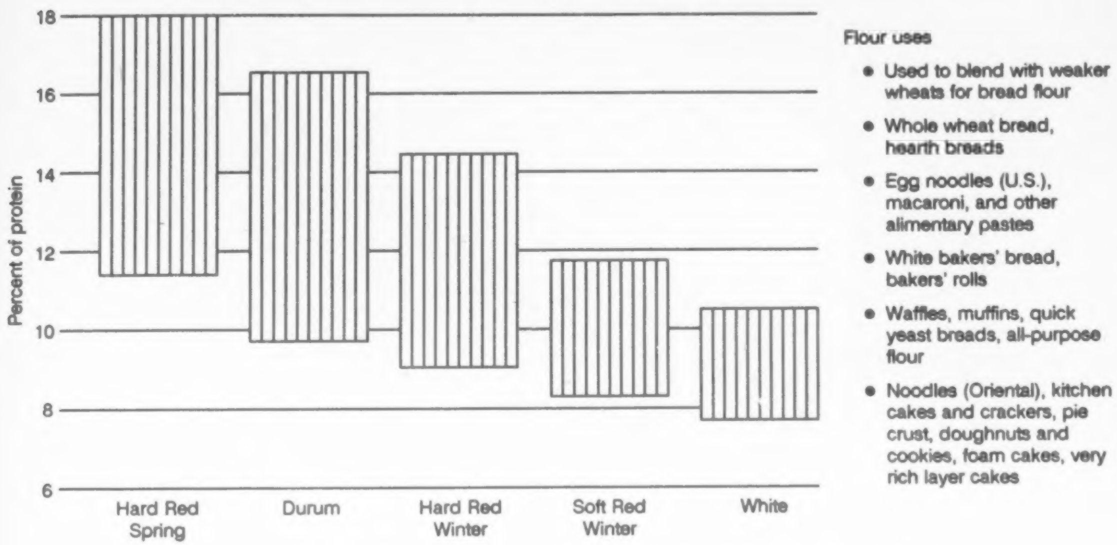
(see ch. 3) is also blended to meet the specific quality demands placed on flour. Information on protein quantity and quality along with other important quality characteristics such as the amount of alpha amylase (as measured by the falling number test), dough handling properties (as measured by farinograph, mixograph, extensograph, and alveograph tests), and bake test results are all used to determine the quantities of each wheat type that will go into the blend.

To produce a hearth bread, spring and winter/spring mixes may be required. Spring, winter/spring mixes, and winter wheats are used for buns and rolls. Pan bread uses winter, winter/spring mixes, and spring wheat. Cakes and pastries may use red and white soft wheat, low-protein winter, and blends of other wheat types. In addition, U.S. winter wheats with various attributes from various regions may be blended with spring wheats. Blending wheats from various origins, types, and intrinsic characteristics allows millers to produce flour to meet various flour specifications, maximize the milling operation, and produce uniform, consistent flour quality.

To illustrate this point further, the OTA overseas questionnaire collected information on the primary reason for importing wheat. Five basic reasons were suggested:

1. to supplement the volume of domestic wheat,

Figure 4-8.—Protein Range and Flour Uses of Major Wheat Classes



NOTE: Flour uses are approximate level of protein required for specified wheat products. Durum is not traded on basis of protein content.

SOURCE: U.S. Department of Agriculture, Economic Research Service, "Wheat Background for 1985 Farm Legislation," Agricultural Information Bulletin No. 467, September 1984.

Table 4-2.—Regional Tastes and Preferences for Wheat-Based End Products and Their Requirements

Region	Major products consumed	Averaged required protein level (in percent)	Types of wheat used
Fast East Asia	Pan bread	12-14	Hard red
	Steamed products	10-11	Medium-hard
	Noodles	9-11.5	Medium-hard white
	Chappatis	9-10	Soft to medium-hard white
Middle East and North Africa	Bread		Durum, medium-hard white and red
	Couscous, pasta, bulgur, fereek	9-11	Durum
Europe	White pan bread	10-12	Hard red, domestic soft
	Rolls	9.5	
	Pasta		Durum
Latin America	Breads	10-14	Hard red, domestic soft
	Pasta		Durum

SOURCE: Canada Grains Council, *Wheats of the World* (Winnipeg, MB, 1979).

2. to supplement quality for blending with domestic wheat,
3. qualities are not available in domestic wheat,
4. as feed, and
5. local wheat is not available.

As more than one reason may apply to a particular country, respondents were asked to indicate all that applied. The results indicate that 51 percent import wheat to supplement volume, 32 percent to supplement quality, 47 percent because quality is not available in domestic wheat, 6 percent for feed, and 13 percent because local wheat is not available.

Importers' preferences for bread, soft, and Durum wheats from all countries exporting these types were also evaluated. Each respondent was asked to rank their preference assuming that price, transportation, and other related costs were equal. Overall the United States did not rank as first choice, even though some respondents did identify it as first choice. The average for all responses is shown in table 4-3.

When identifying important wheat attributes, the demands placed on flour quality must be considered. Flour is used to produce a large number of products under various baking conditions. Advances in milling technology have enabled millers to increase the water absorption of flour so bread yield can be increased. Flour protein levels can also be modified by air classification. This process separates low-protein flour for use in cakes and pastries from high-protein flour that can be used to blend with other flours (2). In addition to traditional leavened bread, many countries produce a variety of unleavened products using weaker flour and chemical leavening.

Flour is classified according to strength, ranging from strong to weak (7). Strong flours have relatively high protein and elastic gluten and can be baked into loaves that have good crumb, grain, and texture. They require considerable water to make a dough that produces a high-yield bread. Doughs from strong flours have excellent handling properties. They are not critical in their mixing and fermentation properties, and yield good bread over a wide range of baking conditions.

Weak flour, on the other hand, has relatively low protein, weak gluten, and low water absorption; it yields dough of inferior handling quality for bread baking, and mixing and fermentation requirements are critical. Weak flours, therefore, require less mixing and fermentation than strong flours and can be used to bake biscuits, crackers, and pastry. Intermediate flour strengths can be considered all-purpose flours for use in traditional household applications.

Baking technologies also influence flour attributes. Chemical and mechanical dough development processes require lower flour protein and weaker gluten than straight (traditional) dough processes. Since flour can be used for home use, in small bakeries, and in highly mechanized plants, knowledge of intrinsic wheat attributes along with how the flour will be baked are required in order to produce a quality flour.

Since no one set of values—high v. low protein or strong v. weak flour—meets the needs of all products, the survey questionnaire was used to determine which attributes and/or tests are important to wheat millers here and abroad. No effort was made to determine levels since they vary by product, country, and baking technology.

Traditionally, wheat class has been used as a quality indicator. Spring wheats have traditionally been high-protein, strong gluten wheats used to make products requiring strong flours and for blending with other wheat types. Soft wheats, which are lower in protein, are used in products requiring weak flour. Domestic and overseas millers were asked if "wheat class is

Table 4-3.—Importers Preference for Wheat by Type and Source

Bread-type wheats	Soft-type wheats	Durum wheats
1. Canadian spring	1. Australian standard white	1. Canadian
2. Australian prime hard	2. U.S. white	2. U.S.
3. U.S. spring	3. U.S. soft red	3. Argentinian
4. U.S. hard red winter	4. Australian soft white	4. EC
5. Australian hard	5. EC soft	
6. Argentinian hard		
7. EC soft		
8. U.S. soft red		

SOURCE: OTA Overseas Wheat Survey, 1988.

a good indicator of wheat quality"; both groups indicated that wheat class alone is not a satisfactory indicator of quality.

In an effort to identify the importance of various attributes and/or tests to domestic millers, the survey listed 28 attributes and/or tests not currently found in the wheat standard. As in the wheat standard analysis, the 28 items were evaluated by flour type and an analysis was made between capacities for domestic millers.

Other than attributes and/or tests not normally used for a particular flour type, no significant differences were found between flour types. Slightly more variability between flour types was evident in the under-5,600-cwt category, and overall rankings varied on some items between capacities (figure 4-9). Eight items (protein, mycotoxins, alpha amylase, falling number, pesticide residue, hidden/dead insects, flour protein, and bake test) were ranked as 6 (moderately important) by the over-5,600-cwt capacity companies. Only mycotoxins, pesticide residue, and hidden/dead insects were ranked as 6 or higher by the smaller companies.

In the overseas questionnaire, only 22 attributes and/or tests were included. Most respondents did not rank the items using the 1 to 7 scale but merely checked the important ones. The importance ranking is therefore based on the frequency with which they responded.

Significant differences exist between items, but more importantly between regions of the world (figure 4-10). For example, protein and alpha amylase were considered the most important by Far East countries. This compares with protein, the falling number test, starch damage, and flour yield in the European Community (EC). Overall, the Far Eastern countries ranked the majority of the items as more important, followed by EC, South America, and then the Middle East.

The frequency with which the 28 items were included in domestic contracts was also examined. Overall, 70 percent of those responding (but 88 percent of the 5,600-cwt-and over category) indicated that one or more items were included in contracts. Five items (protein, hidden/dead insects, pesticide residue, falling number, and farinogragh) were identified as being contracted for most frequently.

Only 14 of the 22 attributes and/or tests listed in the overseas questionnaire are included in contracts. Sixty-two percent of those responding indicated that protein is specified in each contract. Of the remaining 13 items, 23 percent indicated they specify limits for one or more. The falling number test and radiation ranked first (45 percent) followed by the farinograph test (36 percent), pesticide residue (18 percent), and mycotoxins (18 percent).

Both groups indicated additional tests are needed, as demonstrated by their responses on whether the wheat standard adequately addresses their needs. The falling number test and pesticide residue were the main items identified by both groups (figure 4-11). Domestic millers also marked hidden/dead insects for inclusion. Overseas millers identified tests for dough handling properties (farinograph, extensograph, alveograph, and amylograph) for inclusion, while domestic millers did not indicate any preference for these tests even though they often contract for the farinograph.

Corn

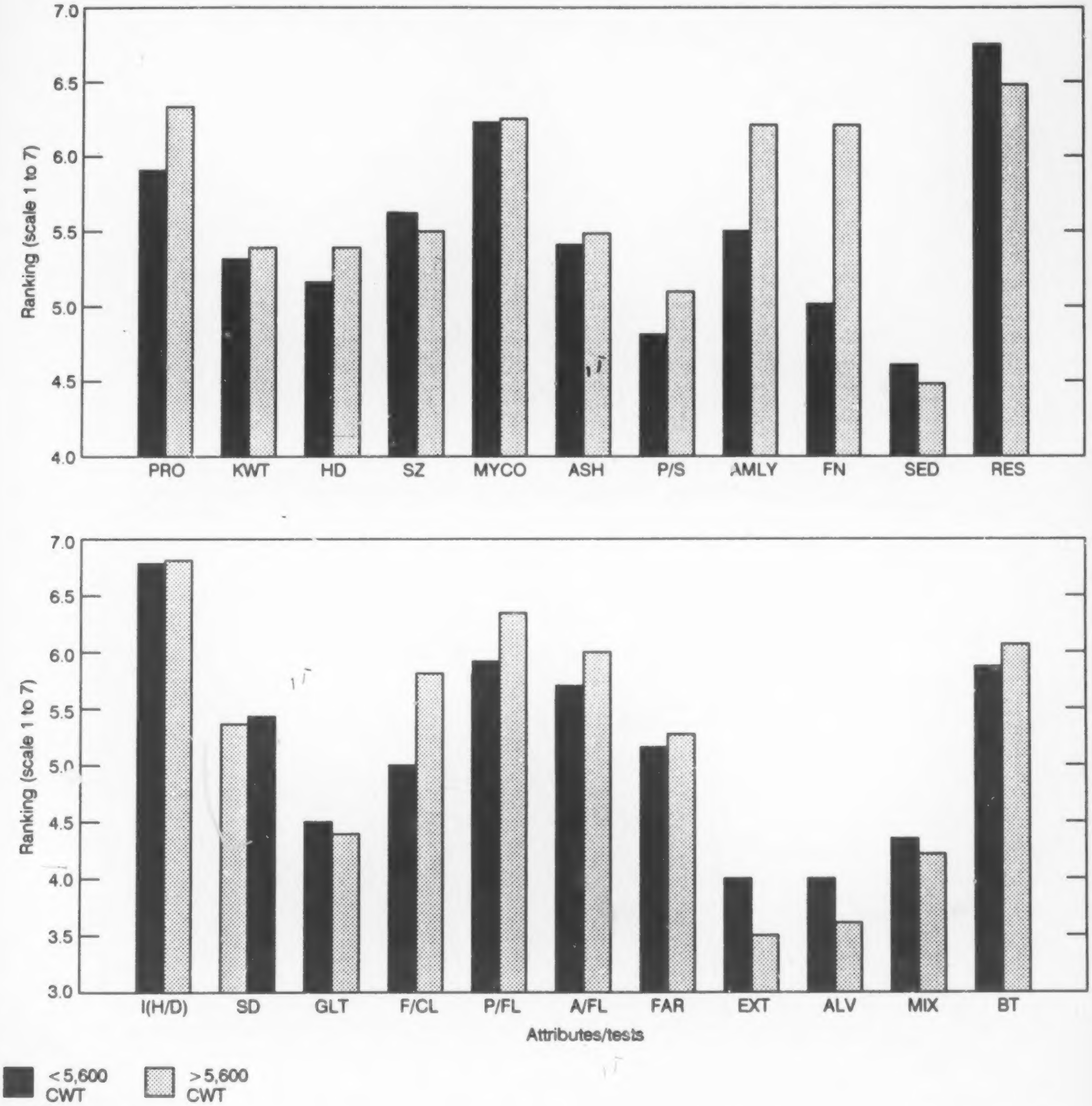
Three main industries account for the majority of corn usage and each one has different requirements. The following is a brief discussion of the important attributes for each industry.

Corn Dry Milling

Several factors affect dry milling performance, yields, and the quality of products derived from dry milling. These factors include:

- corn hardness;
- drying temperature;
- stress cracks;
- broken corn and foreign material;
- kernel size and shape; and
- wholesomeness or freedom from molds, aflatoxin, insects, rodent excreta, toxic substances, odors, and so on.

Figure 4-9.—Importance of Wheat Attributes and/or Tests — Domestic Millers

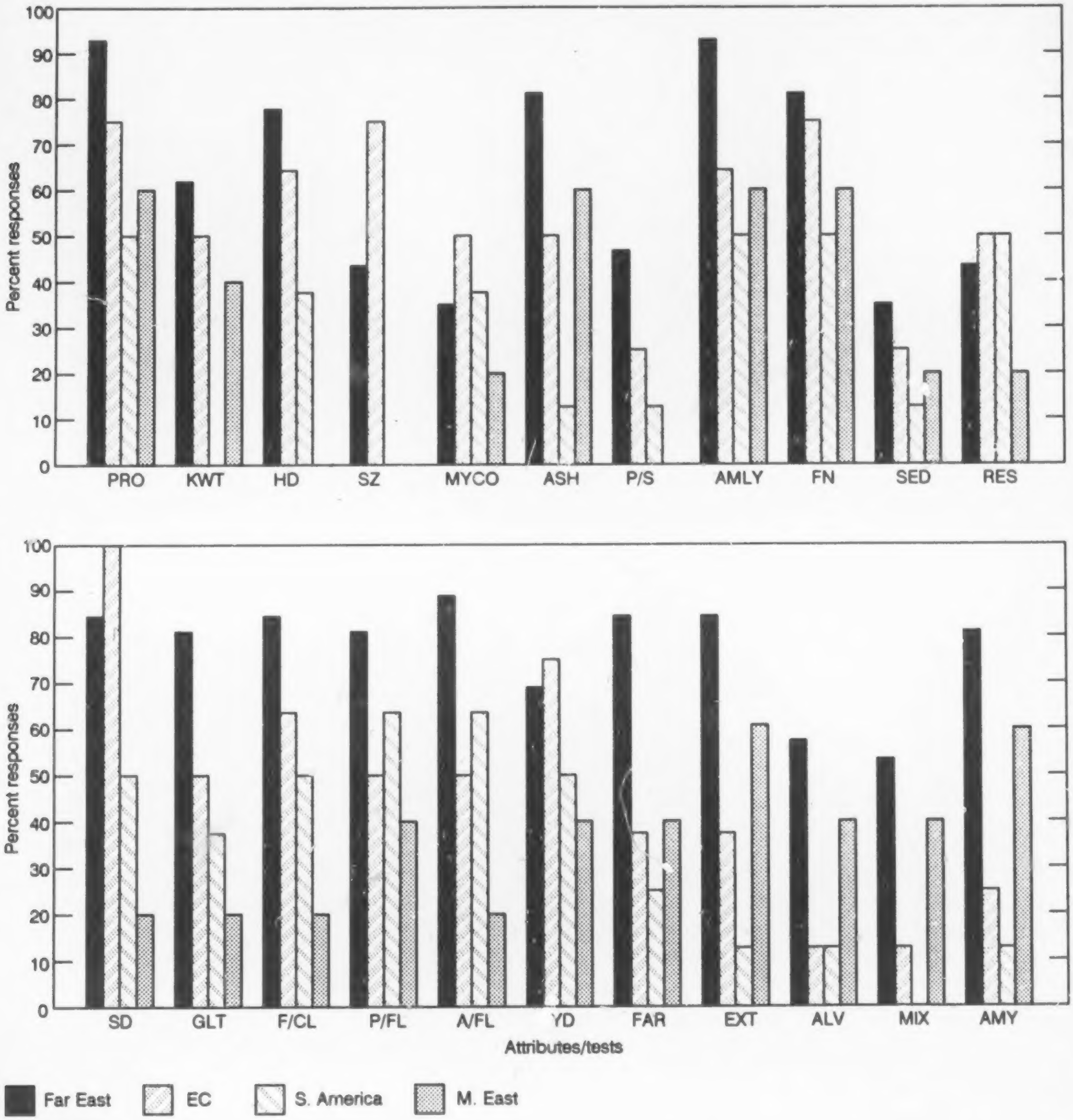


ABBREVIATIONS:

PRO = Protein
KWT = 1,000 kernel weight
HD = Hardness
SZ = Kernel size
MYCO = Mycotoxins
ASH = Wheat ash
P/S = Particle size
AMLY = Alpha amylase
FN = Falling number
SED = Sedimentation
RES = Pesticide residue
I(H/D) = Insects (hidden/dead)
SD = Starch damage
GLT = Wet/dry gluten
F/CL = Flour color
P/FL = Flour protein
A/FL = Flour ash
FAR = Farinograph
EXT = Extensograph
ALV = Alveograph
MIX = Mixograph
BT = Baking test

SOURCE: Office of Technology Assessment, 1989.

Figure 4-10.—Importance of Wheat Attributes and/or Tests — Overseas Millers

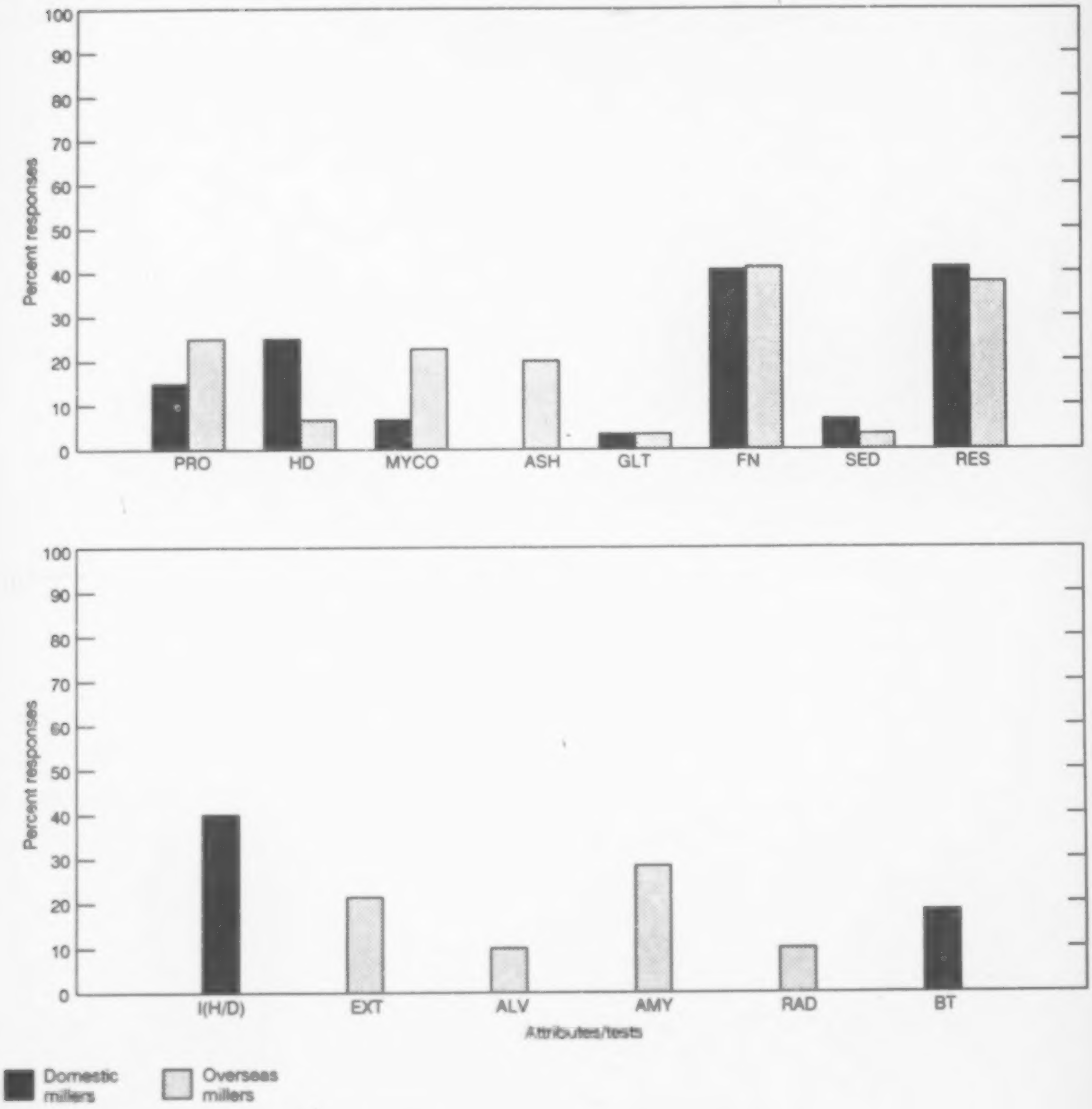


ABBREVIATIONS:

PRO = Protein
KWT = 1,000 kernel weight
HD = Hardness
SZ = Kernel size
MYCO = Mycotoxins
ASH = Wheat ash
P/S = Particle size
AMLY = Alpha amylase
FN = Falling number
SED = Sedimentation
RES = Pesticide residue
SD = Starch damage
GLT = Wet/dry gluten
F/CL = Flour color
P/FL = Flour protein
A/FL = Flour ash
YD = Flour yield
FAR = Farinograph
EXT = Extensograph
ALV = Alveograph
MIX = Mixograph
AMY = Amylograph

SOURCE: Office of Technology Assessment, 1989.

Figure 4-11.—Additional Tests for Inclusion in Wheat Standards[a]



ABBREVIATIONS:

PRO = Protein
HD = Hardness
MYCO = Mycotoxins
ASH = Wheat ash
GLT = Wet/dry gluten

FN = Falling number
SED = Sedimentation
RES = Pesticide residue
I(H/D) = Insects (hidden/death)
EXT = Extensograph

ALV = Alveograph
AMY = Amylograph
RAD = Radiation
BT = Baking test

[a] Percentages are based on number of responses that indicated additional tests are needed

SOURCE: Office of Technology Assessment, 1989

Corn hardness can be defined as the quantity of vitreous or horny endosperm contained in a corn kernel relative to the amount of floury endosperm. Corn hardness is almost entirely a result of corn genotype, but to a limited extent nitrogen, soil fertility, and drought can cause hardness to increase. Dry millers need a hard corn in order to produce high yields of large flaking grits and have even developed approved lists of corn hybrids.

Excessive drying temperatures can lead to corn kernel stress cracking, which has deleterious effects on dry milling yields. The stress crack formation in the horny endosperm is caused by rapidly drying kernels with heated air. Stress-cracked corn not only causes increased breakage during handling, but also reduces flaking grit yields since stress-cracked flakes produce smaller grits when undergoing cooking and pressing through flaking rolls.

Broken corn and foreign material is detrimental to dry milling and no attempt is made to use this material in the milling process. It is removed prior to milling and diverted to hominy feed. Broken kernels affect the tempering process because they absorb moisture faster than whole kernels. Kernel size, shape, and color also affects the dry milling process. Round kernels are more difficult to degerm than flat kernels, and the same is true of small kernels compared with large ones. Color is important to producing corn chips because the alkali cooking process modifies the color. In some cases white and yellow kernels are blended to produce the desired color (5).

Corn Wet Milling

Since the wet milling process involves steeping with elevated temperatures and sulfur dioxide, fungi and other micro-organisms are destroyed (4). Many of the other wholesomeness factors such as insects, mycotoxins, and other debris are not found in the food product after processing but can be found in the feed byproducts if they are present in the corn being processed.

High levels of broken corn and foreign material, breakage susceptibility, and damaged kernels are not desired by the wet milling industry. Broken corn must be removed prior to processing because it affects steeping. High levels of mold-damaged kernels affects germ recovery and crude oil quality. Drying temperature, as discussed in the dry milling section, causes stress cracking and increases breakage susceptibility, which affects starch recovery.

Feed Manufacturing

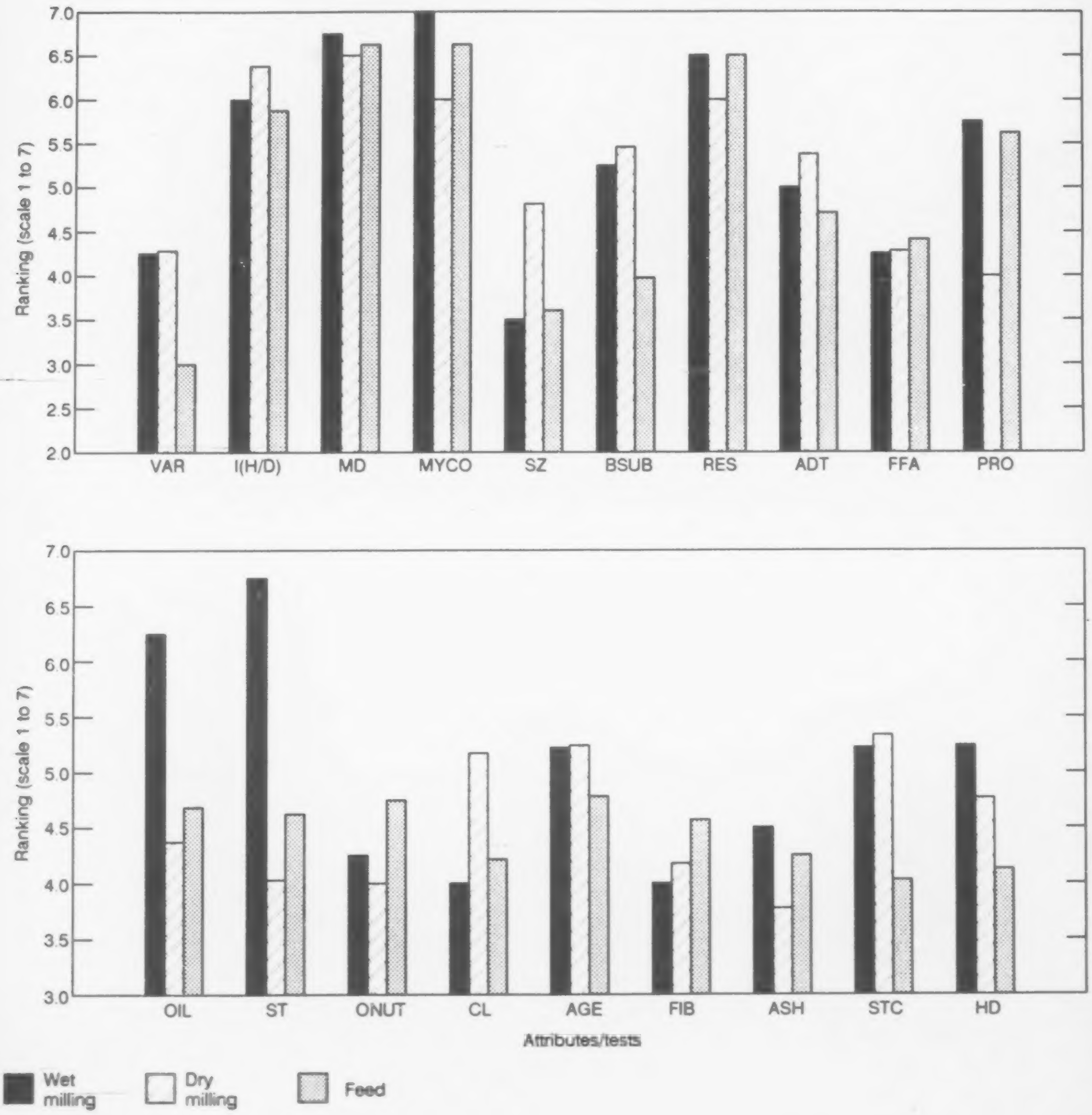
All feed grains are highly palatable to livestock. Corn has the lowest protein content of all feed grains. However, the protein in all feed grains has a relatively low biological value for monogastric animals due to a deficiency of one or more essential amino acids. When formulating diets for poultry and swine, therefore, supplemental protein that adds sufficient amino acids to balance this deficiency must be added. Also, feed grains are extremely low in calcium content and in phosphorus, and deficient in several essential vitamins (6). Therefore, these deficiencies must also be overcome with supplements in various degrees, depending on the type of animal to be fed (3).

Properly balanced diets containing wholesome ingredients are necessary for efficient livestock production. In addition, variations in important intrinsic properties (protein, crude fiber, total digestible nutrients) from published values are detrimental to efficient feed production.

Survey Results

The OTA questionnaire sent to dry millers, wet millers, and the feed manufacturers listed 19 attributes and/or tests not currently found in the corn standard (figure 4-12). With the exception of starch and oil content in the wet millers' rankings, all three industries ranked hidden/dead insects, mold, mycotoxins, and pesticide residue as the most important items. Breakage susceptibility, stress cracks, and hardness, as expected, were ranked higher by wet and dry millers than by feed manufacturers. Protein is considered more important by wet millers and feed manufacturers. Oil and starch content were considered very important by wet

Figure 4-12.—Importance of Corn Attributes and/or Tests



ABBREVIATIONS:

VAR = Variety
I(H/D) = Insects (hidden/dead)
MD = Mold
MYCO = Mycotoxins
SZ = Kernel size

BSUB = Breakage susceptibility
RES = Pesticide residue
ADT = Artificial drying temperature
FFA = Free fatty acid
PRO = Protein

OIL = Oil
ST = Starch
ONUT = Other nutrients
CL = Color
AGE = Age

FIB = Fiber
ASH = Ash
STC = Stress cracks
HD = Hardness

SOURCE: Office of Technology Assessment, 1989

millers, but only marginally important by dry millers and feed manufacturers.

Seventy-one percent of the wet and dry millers and 36 percent of feed manufacturers indicated that limits for one or more of the 19 items were being included in contracts. Five items (hidden/dead insects, mold, mycotoxins, pesticide residue, and stress cracks) were found most often in contracts by all industries.

Data from the survey of importers only involved the attributes and/or tests that are included in contracts. Stress cracking was the only one identified by dry millers as having limits included in contracts, whereas five items (protein, fiber, starch, oil, and mycotoxins) were marked by wet millers being included. Overseas feed manufacturers specify limits on four items (protein, fiber, energy, and carbohydrates) in contracts.

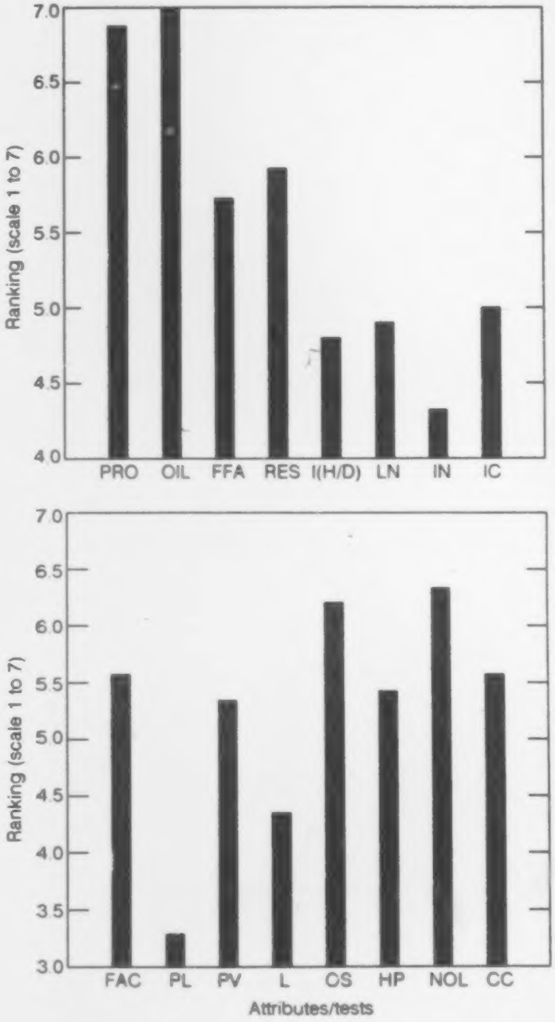
Soybean Processing

The quantity and quality of soybean protein and oil are important attributes to processors since the main products are high-protein meals and oil. Crude soybean oil contains oil-insoluble and oil-soluble impurities that must be removed (1). Oil-insoluble impurities include seed fragments, excess moisture, and waxy fractions that make oil cloudy. Oil-soluble impurities such as free fatty acid, phosphatides, and protein fractions are detrimental to the oil's flavor, odor, color, and stability.

Of 16 attributes and/or tests not currently contained in the soybean standard, soybean processors ranked protein, oil, oil stability, and neutral oil loss as most important (figure 4-13). No limits for any of the 16 items listed, however, are included in contracts.

For overseas soybean processors the importance of items and which items have limits included in contracts were evaluated. Protein, oil and free fatty acid were considered the most important and the only items for which limits are included in contracts.

Figure 4-13.—Importance of Soybean Attributes and/or Tests



ABBREVIATIONS:

PRO = Protein
OIL = Oil
FFA = Free fatty acid
RES = Pesticide residue
I(H/D) = Insects (hidden/dead)
LN = Lovibond number
IN = Iodine number
IC = Iron content

FAC = Fatty acid content
PL = Phosphorous level
PV = Peroxide value
L = Lipoxygenase
OS = Oil stability
HP = Hydratable phosphatides
NOL = Neutral oil loss
CC = Chlorophyll content

SOURCE: Office of Technology Assessment, 1989

UNIFORMITY BETWEEN SHIPMENTS

Delivering uniform, consistent quality between shipments has been identified by overseas and domestic industries as important. U.S. industries have more flexibility in handling a shipment that is not up to specification, since the grain can be resold or blended. Many overseas industries cannot do this since they have little or no inventory and each time a shipment arrives they must deal with the quality received.

The need for uniform or consistent quality was documented at the International U.S. Wheat End Use Quality Conference in June 1986 by Dr. Seiichi Nagao from the Nisshin Flour Milling Co., Ltd., Japan, and by Emma B. Laguio, United Flour Mill Co., Ltd., Bangkok, Thailand. Dr. Nagao stated:

> The low reliability of U.S. Hard Red Spring wheat is caused by wide fluctuation both in milling and in baking performance, and it seems to me that the quality fluctuation among cargoes is getting larger and more serious. . . .Besides ash content, almost all quality items including test weight, moisture, protein, flour, yield, the analytical data of flour and baking performance vary very widely. As we are afraid of giving our large customers trouble in their automated baking process by blending a large amount of U.S. Hard Red Spring wheat that varies widely in its baking absorption and dough handling property, it is thought to be a supplementary material usable only with No. 1 Canada Western Red Spring wheat which is more stable in quality (8).

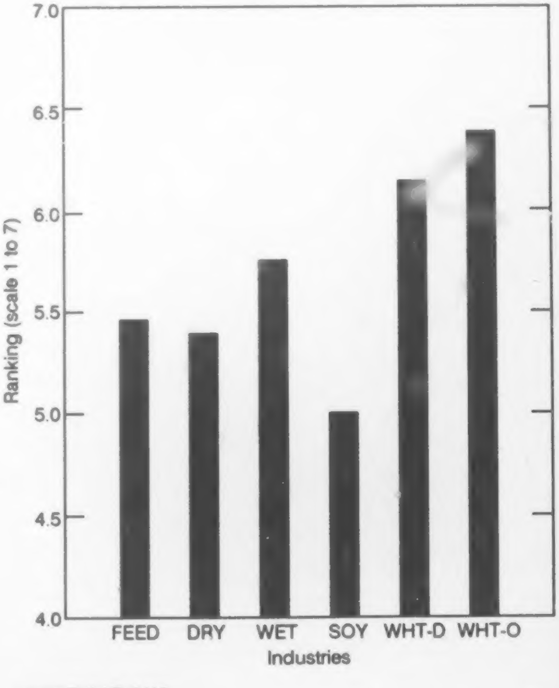
Emma Laguio echoed Dr. Nagao but added that consistency in quality is foremost in the Asian miller's mind.

> Bakers in our region require consistency of quality in flours they use. Flour millers also require consistency of quality in the wheat they will mill. I realize that the attainment of consistent or even near-consistent wheat quality at any given time calls for more than just the acts of mortals. However, there are factors within the producer's control which can and do contribute to quality consistency in wheat. This, I believe is particularly important to Asian millers who are a captive market, so to speak, in the sense that we are obligated to mill whatever wheat we receive (8).

When identifying important grain quality attributes, the system's ability to consistently deliver these attributes can be as big a factor as the attribute itself, as evidenced by these importers' statements. The qualities desired are generally available, given the information collected from the OTA survey. But quality fluctuations between shipments can affect purchasing decisions and the ultimate use of a particular grain.

As part of the OTA survey, each industry was asked to rank the importance of uniformity between shipments (figure 4-14). Domestic and overseas wheat millers ranked the importance of uniformity between shipments as 6 (moderately important) or higher. The wet millers con-

Figure 4-14.—Importance of Uniformity Between Shipments



ABBREVIATIONS:
FEED = Feed manufacturers
DRY = Dry millers
WET = Wet millers
SOY = Soybean processors
WHT-D = Wheat millers (domestic)
WHT-O = Wheat millers (overseas)

SOURCE: Office of Technology Assessment, 1989

sidered uniformity more important than the other corn industries did, while the soybean processors ranked it as 5 (slightly important).

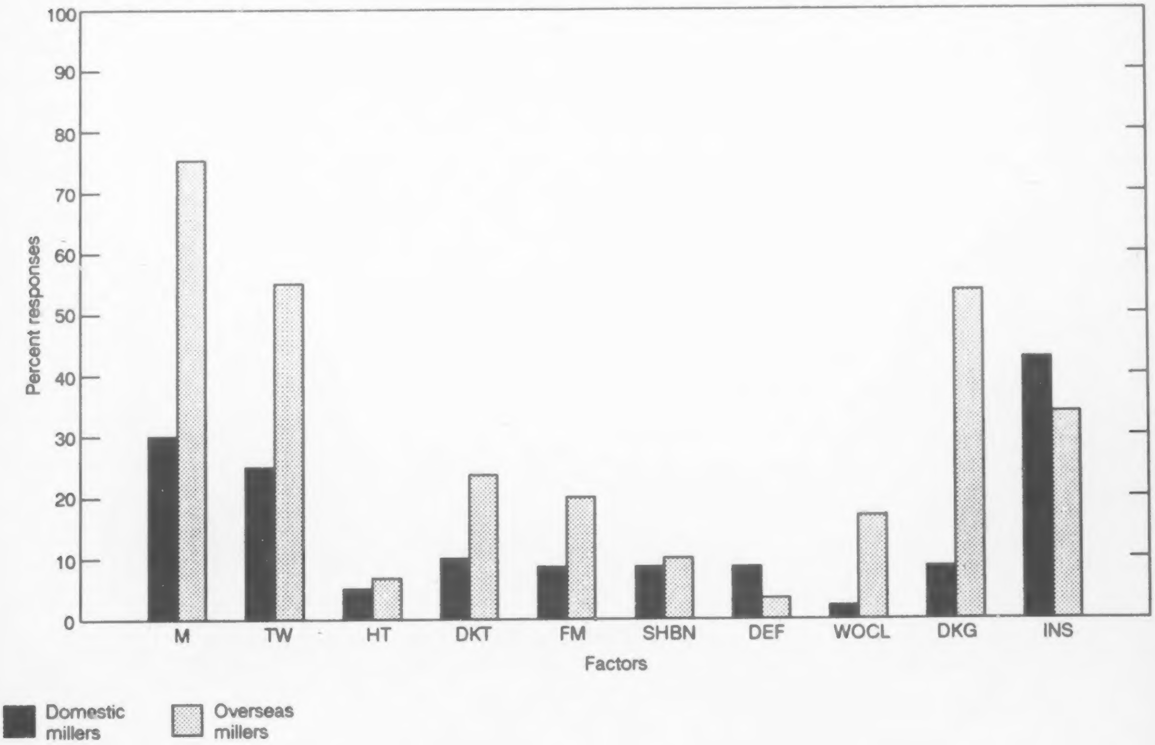
When evaluating future attributes/and or tests for grain, the ability to deliver uniform, consistent quality must be addressed. The importance of delivering consistent quality is evident when examining the factors currently contained in each standard. Significant concern exists for these factors regarding uniformity (figures 4-15, 4-16, and 4-17).

For wheat, moisture, test weight, dockage, and live insects stand out as being critical factors regarding uniformity between shipments to overseas buyers. With the exception of dockage, these factors are also considered the most important in terms of uniformity between shipments to domestic millers.

Except for moisture, the importance of each factor varies by individual corn industry. Moisture was considered the most important factor overall in terms of uniformity, followed by damaged kernels total.

The importance of uniformity between shipments for attributes and/or tests not currently found in the grain standards again reflects the industries' concerns. Protein content, in the case of wheat, was considered the most important by domestic and overseas millers. Overseas millers showed more concern for dough

Figure 4-15.—Importance of Uniformity on Wheat Standard Factors

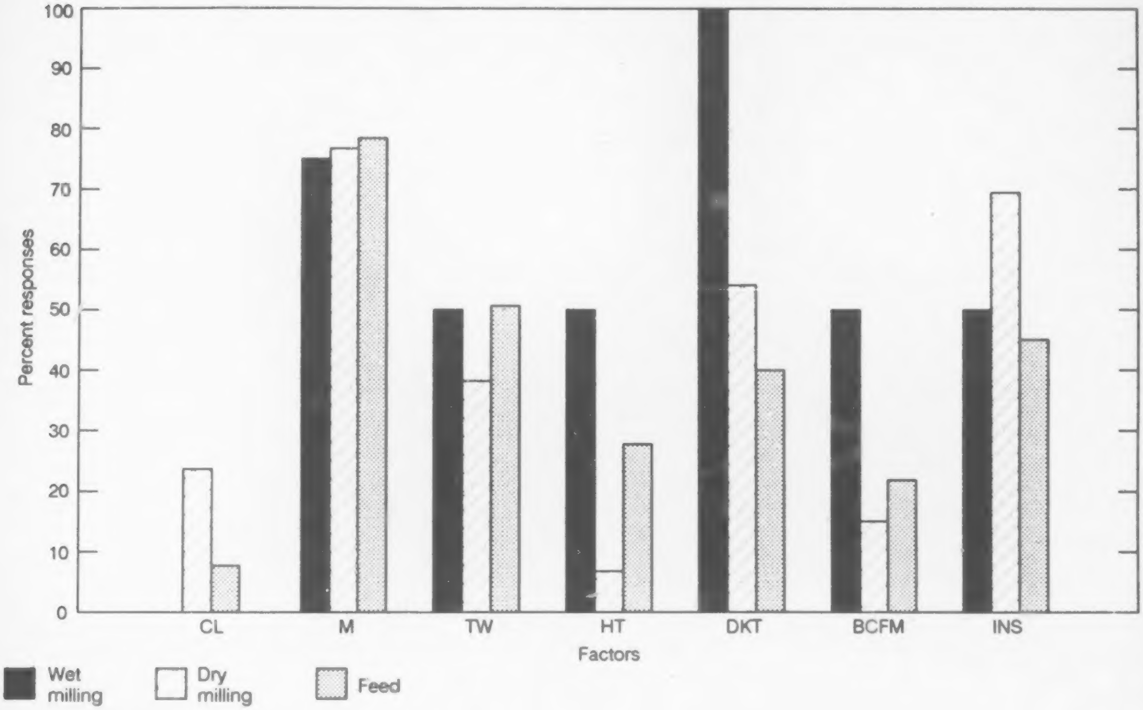


ABBREVIATIONS:

M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
FM = Foreign material
SHBN = Shrunken and broken kernels
DEF = Total defects
WOCL = Wheat of other classes
DKG = Dockage
INS = Live insects

SOURCE: Office of Technology Assessment, 1989

Figure 4-16.—Importance of Uniformity on Corn Standard Factors



ABBREVIATIONS:

CL = Class
M = Moisture
TW = Test weight
HT = Heat damage
DKT = Damaged kernels (total)
BCFM = Broken corn and foreign material
INS = Live insects

SOURCE: Office of Technology Assessment, 1989

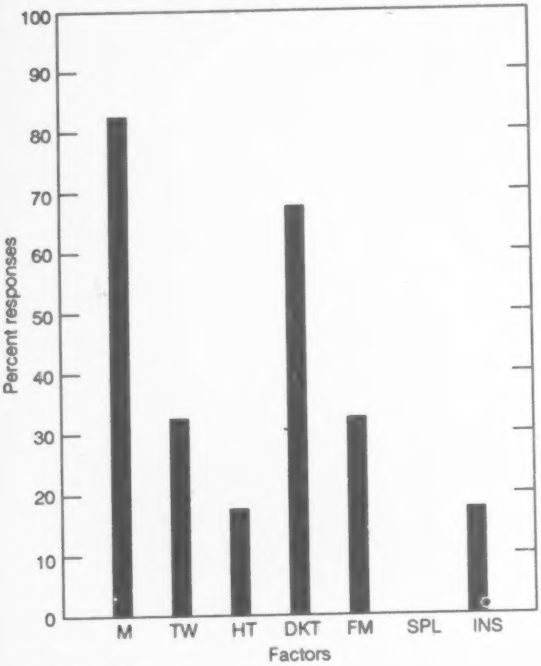
handling tests than did domestic millers, but domestic millers ranked the bake test second in importance. Except for mycotoxins, the three corn industries ranked the items differently, with concerns being evident for the items of particular interest to each. Soybean processors, on the other hand, did not identify any item as being overly important.

DECREASE IN QUALITY

Each industry was asked in the OTA survey if quality has decreased as evidenced by any of the factors contained in the grain standards or for the attributes and/or tests listed. The domestic and overseas wheat millers indicated that they have perceived a decline in quality.

Sixty-six percent of the overseas respondents indicated that they have experienced a decrease in wheat quality. Five factors (moisture, heat damage, foreign material, wheat of other classes, and dockage) were identified as having gotten worse. Domestic millers also identified these factors, but ranked four others (test weight, damaged kernels total, shrunken and broken kernels, and live insects) as the areas showing declines. Both groups indicated that quality has decreased in terms of protein and

Figure 4-17.—Importance of Uniformity on Soybean Standard Factors



ABBREVIATIONS:

M = Moisture
TW = Total weight
HT = Heat damage
DKT = Damaged kernels (total)
FM = Foreign material
SPL = Splits
INS = Live insects

SOURCE: Office of Technology Assessment, 1989

the falling number test. Overseas millers also identified wet/dry gluten and the farinograph test, whereas domestic millers expressed concerns for the presence of hidden/dead insects.

The results from the survey regarding decreases in wheat quality were also reported by Emma Laguio (tables 4-4 and 4-5), who pointed out at the International End Use Quality Conference that test weight, kernel size, and kernel hardness have been decreasing over time. Lower water absorption and shorter mixing times of spring wheat, as demonstrated by the farinograph test, have been evident since 1983. Further, it was reported that 1985 and 1986 arrivals show significantly lower water absorption and mixing time as compared with the shipments of the 1970s, and that flour doughs are softer and slightly more extensible. These conditions, in his opinion, indicate lower gluten strength.

FINDINGS AND CONCLUSIONS

All processors desire grain that is free from pesticide residues, molds, mycotoxins, toxic weed seeds, and insects and insect fragments, and that otherwise is in a sanitary condition. The importance, however, of physical and intrinsic quality characteristics can vary by grain and by processor and are influenced by the grain's ultimate use. Each industry, domestic and overseas, defines quality in terms of the areas important to its market, as the OTA survey of buyers confirmed.

Standards

Domestic and overseas wheat millers consider the factors contained in the wheat standard important, but indicated a need for additional tests. However, overseas millers generally consider the factors contained in the standard as slightly more important. Live insects were considered the most important factor by both. Domestic millers include in their contracts limits for the factors contained in the standard more often than overseas millers, who purchase on grade only with limits.

Overall each corn industry considers the factors contained in the standard as important. Differences exist between industries regarding the importance of each factor, but wet millers consistently ranked the factors higher than dry millers and feed manufacturers did. Differences

Table 4-4.—Quality Characteristics of U.S. No. 2 or Better DNS, 15 Percent Protein, 1975-86 Shipments to Thailand

	1975	1978	1981	1983	1984	1985	1986
Wheat characteristics:							
1,000 kernel weight (g)	29.2	31.4	32.4	32.1	31.9	28.3	27.4
Grain hardness (%)	—	13.2	12.4	11.5	12.3	15.2	15.2
Moisture (%)	12.1	12.5	13.0	11.8	11.2	11.6	12.3
Ash (%)	1.50	1.52	1.53	1.64	1.63	1.59	1.60
Protein (%, as is M.B.)	15.2	15.1	14.7	15.0	15.0	15.0	15.2
Protein (%, 12.0% M.B.)	15.2	15.2	14.9	15.0	14.9	14.9	15.2
Flour characteristics (milled in Buhler Mill MLU-2020):							
Flour extraction (%)	—	73.0	73.5	73.4	74.1	72.6	70.6
Ash (%)	0.53	0.41	0.42	0.51	0.48	0.46	0.46
Protein (%, 13.0% M.B.)	14.5	14.5	13.8	14.2	14.0	14.2	14.2
Wet gluten (%)	40.2	38.5	37.5	38.2	38.0	38.0	39.5
Amylogram peak viscosity (BU)	—	620	545	728	869	805	500
Farinogram:							
Absorption (%)	69.3	68.8	67.5	66.0	65.4	64.3	64.9
Peak time (min.)	14.5	11.5	11.5	8.0	9.5	9.5	8.5
Mixing tolerance index (BU)	25	15	15	20	20	25	25
Stability (min.)	20	26	26	16	20	25	20
Valorimeter (BU)	87	90	92	77	85	89	89
Extensogram:							
45 minutes							
Extensibility (mm.)	232	240	244	262	242	235	236
Resistance (BU)	240	265	275	256	324	299	320
Area (sw. cm.)	127	150	161	174	188	186	192
135 minutes							
Extensibility (mm.)	181	214	218	246	255	235	240
Resistance	480	345	320	283	382	386	400
Area (sq. cm.)	176	171	209	218	222	230	217

SOURCE: U.S. Wheat Associates, "U.S. Wheat End Use Quality Conference," published proceedings, Washington, DC, June 1986.

Table 4-5.—Quality Characteristics of U.S. No. 2 or Better HRW, 11 Percent Protein, 1981-86 Shipments to Thailand

	1981	1982	1983	1984	1985	1986
Wheat characteristics:						
1,000 Kernel weight (g)	30.5	31.7	31.6	31.7	31.2	28.9
Grain hardness (%)	11.4	11.8	12.5	14.2	16.1	16.5
Moisture (%)	10.0	10.6	11.2	11.1	11.4	10.9
Ash (%) 1.50	1.53	1.47	1.51	1.55	1.44	1.55
Protein (%, as is M.B.)	11.9	12.0	11.8	12.2	12.0	11.8
Protein (%, 12.0% M.B.)	11.6	11.8	11.7	12.1	11.9	11.6
Flour characteristics (milled in Buhler Mill MLU-202):						
Flour extraction (%)	72.0	71.0	72.3	75.6	71.9	73.4
Ash (%) 0.53	0.40	0.41	0.46	0.46	0.43	0.44
Protein (%, 13.0% M.B.)	10.8	10.7	10.8	11.1	10.9	10.5
Wet gluten (%)	28.6	29.6	29.8	31.2	30.0	20.4
Amylogram peak viscosity (BU)	655	790	760	800	600	700
Farinogram:						
Absorption (%)	63.3	63.2	62.0	63.5	62.1	60.1
Peak time (min.)	4.0	6.5	5.25	6.0	6.5	1.75
Mixing tolerance index (BU)	20	30	30	25	25	10
Stability (min.)	15	13	12	16	15	17
Valorimeter (BU)	71	68	66	74	69	51
Extensogram:						
45 minutes						
Extensibility (mm.)	200	207	200	215	219	185
Resistance (BU)	265	350	290	320	310	330
Area (sw. cm.)	116	156	146	142	144	122
135 minutes						
Extensibility (mm.)	189	203	207	204	192	179
Resistance	318	390	331	382	390	440
Area (sq. cm.)	130	178	158	175	168	160

SOURCE: U.S. Wheat Associates, "U.S. Wheat End Use Quality Conference," published proceedings, Washington, DC, June 1986.

also exist between industries concerning which factors are included in contracts. The factors having limits included in contracts by domestic processors are similar to those of their overseas counterparts, however.

A number of factors currently in the soybean standards are not considered important by processors. These include class, test weight, and splits. Moisture and heat damage are considered the most important factors by domestic processors, while overseas processors consider moisture and foreign material as important.

Important Attributes Not in Standards

No one set of quality attributes—e.g. high v. low protein or strong v. weak flour—meets the demands for all wheat products. Domestic millers do agree, however, that at least eight factors are important no matter what the end-product may be: protein, mycotoxins, alpha amylase, falling number, pesticide residue, hidden/dead insects, flour protein, and bake test. Overseas millers differed by region of the world in their response to which attributes are important. Nevertheless, four factors were common across all regions: protein, pesticide residue, falling number, and dough handling tests. The Far Eastern countries considered these factors to be of greater importance than other regions of the world.

Domestic and overseas wheat millers indicate that additional tests are needed. Falling number and pesticide residue were the items most often identified by both groups. Overseas millers also specified dough handling tests such as farinograph and alveograph as important additional tests, while domestic millers indicate a stong preference for a test for hidden/dead insects.

Determining which attributes are important for corn is industry-dependent except in areas regarding wholesomeness, health, and safety concerns. Quality attributes vary by requirements of each corn industry. Items such as stress cracking, breakage susceptibility, and hardness are more important to wet and dry millers than to feed manufacturers. Attributes such as pesticide residue, mold, mycotoxin, and hidden/dead insects are important to all industries.

Commonality of important quality attributes is more evident in soybeans than in wheat or corn between domestic and overseas processors. The most important attributes are protein, oil, and free fatty acid content.

Uniformity Between Shipments

The grain system's ability to deliver the important quality attributes consistently is as important as the attributes themselves. Quality fluctuations between shipments significantly influence purchasing decisions. Problems with uniformity are especially acute in wheat and corn. Uniformity between shipments will become more important as processing technologies become more sophisticated and more end-uses are found for each grain.

In wheat, overseas millers indicate that the factors contained in the wheat standard that are most affected by lack of uniformity are moisture, test weight, dockage, and live insects. With the exception of dockage, uniformity in these factors was also considered the most important by domestic millers. Protein, dough handling tests, and the bake test were also identified as items of concern.

In corn, moisture was the most important uniformity concern, followed by damaged kernels. Mycotoxin was considered important by all three corn industries, with other concerns being expressed for items of particular interest to each industry.

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Chapter 5

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Chapter 5

The Changing Role of Quality in Grain Markets

The quality concerns of each industry using wheat, corn, and soybeans are identified in chapter 4. Wheat, by its very nature, is the most complex of the three grains in terms of defining quality because of the vast array of products and processing technologies involved. Quality requirements differ not only by type and individual product, but between mills using the same type wheat to produce flour for the same type of product. Corn is somewhat less complex in that fewer products are produced and quality concerns can be traced to the individual industries. Nevertheless, the quality required by one corn industry is not necessarily important to others, so decisions regarding corn quality must be assessed in terms of major usage. Quality concerns of different industries using wheat are somewhat offset by the fact that different types of wheat exhibit different properties. Soybean quality is the least complex, because the vast majority of soybeans are used to produce oil and meal.

The varying quality requirements exhibited by these industries, especially for wheat, highlight the need for the United States to become more aware of individual industry requirements if the goal is to produce and deliver high-quality grain. The Nation has developed the reputation as a consistent supplier for any type and quality of grain desired; to become a supplier of high-quality grains, it must become more quality-conscious and develop a reputation as a supplier of high quality. The U.S. grain industry must understand the specific requirements of its customers in order to deliver the quality requested and must become more aware of the dynamic issues surrounding the qualities required by the marketplace. Areas such as technological advancements in processing technologies, Government policies, customer preference, development of new finished products, and consumption patterns all affect customers' purchasing decisions and their definition of quality at any one point in time.

QUALITY IN THE MARKETPLACE

High quality, as defined by the specific attributes required by each industry, is constantly changing. But the ability to produce and deliver high-quality grain can mean more than just providing grain that meets specific test results. What constitutes high quality from the customer's point of view can range from special handling (low-temperature drying of corn) to the uniformity of specific attributes within and between shipments. The importance of the latter was evident in the OTA survey results and in the statements by overseas wheat millers (ch. 4).

The OTA survey specifically asked respondents to rank the importance of uniform quality between shipments. Domestic and overseas respondents considered uniformity as being important even though they differed on which attributes were more critical. Overseas millers also indicated the importance of uniformity: Canada and Australia stress uniformity between shipments and this often accounts for wheats from these countries being considered first choice.

Even identifying the important quality attributes for specific industries is not simple. Some traditional measuring technologies are not accepted by all industries producing the same product. In the OTA survey, tests for rheological properties (extensograph, alveograph, and mixograph) were considered more important by overseas wheat millers than by domestic ones. Though overseas millers considered these tests key, their importance varies by region of the world. Paul Clark, for example, has indicated that in trying to identify and establish soft wheat flour quality characteristics, Archway Cookies, Inc., found not only that companies had different quality requirements but that different companies keyed on different analytical tests for performance parameters (3).

As processing technologies become more sophisticated through automation or as more demanding qualities are required for finished products, the need for specific attributes within well-defined ranges becomes more critical. Technologies for baking bread, rolls, and similar products in large bakeries have advanced significantly. While bread can be made by hand using low-protein wheat, large dough mixers and other equipment found in large automated bakeries place too much stress on the low-protein flour, which results in unacceptable finished products and the need for different attributes. The way the flour will be baked plays a very important role in determining the specific values for the various attributes required.

In addition to advances in processing technologies, technological advances in other areas can have an impact on the quality required by different industries. For many years, high-protein wheats have been blended with low-protein wheats to strengthen flour. More recently, vital wheat gluten, a product containing 75 to 80 percent protein, has been used as a flour fortifier. The recent expansion of vital wheat gluten production is the result of technological improvements in breadmaking, population growth, and increasing urbanization in some countries. Vital wheat gluten in these nations has become more attractive than higher priced, imported wheat.

Many countries striving to become self-sufficient in wheat production are producing vital wheat gluten to fortify their locally produced low-protein wheat. Some European processors are also producing isoglucose, a sweetener and sugar substitute, from wheat starch (that portion of the wheat kernel remaining after the gluten is extracted), similar to corn sweetener's use in the United States.

Corn, which has always been considered from a feed point of view, is beginning to experience pressures in areas similar to those experienced by wheat. As feed manufacturing becomes more sophisticated and automated, along with the need for strictly controlled balanced diets especially in the poultry industry, the demand for quality attributes and consistency in delivery is of increased importance. In other cases, individual dry and wet corn milling companies are placing more stringent demands on the quality of corn they purchase. Companies are contracting with farmers to grow certain varieties and provide special handling, such as low-temperature drying.

Traditional quality attributes, even though varied, thus may be influenced by technological advances, economic concerns, and Government policies here and abroad. For the United States to produce and deliver high-quality grain, it must not only become increasingly aware of concerns over quality expressed by domestic and overseas industries and match quality to their wishes, but it must understand why importers purchase grain in the first place.

The findings in chapter 4 could lead to the conclusion that the United States should stress developing high-protein wheats. Yet the expanded use of vital wheat gluten in some countries to obtain self-sufficiency provides a completely different picture. Knowledge of customer preference, consumption patterns, and the role of Government policies is critical when considering what direction the United States should take. The rest of this chapter examines these areas using wheat as an example.

CHANGING NATURE OF MARKETS—A CASE STUDY IN WHEAT

As the intensity of competition in grain markets increases, so does the differentiation of important quality characteristics. Because of the dynamic nature of wheat markets, OTA analyzed the demand for wheat quality characteristics in international markets. The analysis had two specific objectives—to identify the extent to which market shares are determined by factors such as relative prices, income, preferences, and other factors, and to analyze preferences for wheat by quality factors and estimate changes in these preferences.*

Background

Various types of wheat are produced around the world based on conduciveness of the local climate. For example, the semiarid climate found around the Mediterranean Sea is particularly suitable for production of Durum wheat. Environmental factors including rainfall, temperatures, soils, available nutrients, and topography influence and cause wide variety in such wheat characteristics as protein content, test weight, and kernel size. Genetics is also a major factor in wheat characteristics. Plant breeding programs differ greatly from one producing area to the next, resulting in wide variations in inherited attributes. Differences in environment and genetics among wheat-producing areas of the world or within a country result in wide variations in the characteristics of wheats produced, even among those of the same general type.

Numerous classes of wheat are available from the major wheat-exporting countries of Argentina, Australia, Canada, France, and the United States (see table 5-1). Although each exports one or more wheat class, the United States is alone in exporting five classes in significant amounts. Hard Red Winter (HRW) has always been the dominant class in U.S. wheat exports, followed by Hard Red Spring (HRS); White and Soft Red Winter (SRW), in varying arrangements—the second through fourth positions. Durum is consistently the class with the lowest export volume. Each of the remaining exporter countries is known for one dominant class or, in the case of France, type. Argentina predominantly exports Trigo Pan whereas Canada has established a reputation with high bread-making quality Canadian Western Red Spring (CWRS). France, a member of the European Community (EC), exports soft wheats. Australian Standard White is by far the dominant class in Australian wheat exports.

The quantity and quality of protein is the most important attribute of wheat in determining end-use suitability. Table 5-2 shows the required protein levels of typical American wheat products and protein ranges for U.S. wheat classes. The overlapping of class protein ranges portrays the possibilities of class substitutions. Differences between protein ranges and realization of protein quality differences between classes reveal the inability of wheat classes to be perfectly substitutable or homogeneous from a technical perspective.

Product Consumption and Wheat Importation

Consumers generally prefer end products that make good use of the characteristics of wheat grown in their local or regional area. Tastes and preferences thus tend to be regionalized by climate and culture (1). In the Mediterranean area, for instance, where Durum wheat is grown, products typically consumed include bread, couscous, bulgur, and fereek, all of which are made from Durum alone or in a blend with common wheat. The Far East provides another example of this behavior. Vast amounts of soft wheat are grown in this region so that noodles, chappatis, and steamed breads join rice as common consumer products.

Flour millers and other wheat product providers in importing countries are well aware of the tastes and preferences in their markets. Millers are interested in buying wheats that em-

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*The analysis is based on William W. Wilson, Paul Gallagher, and Jean Riepe, "Analysis of Demand for Wheat Quality Characteristics," prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

Table 5-1.—Export Classes of Wheat Categorized by Characteristics and Country of Origin

	Characteristics						
	Kernel hardness			Bran color		Habit	
Country/wheat class	Hard	Medium-hard	Soft	Red	White	Winter	Spring
Argentina:							
Trigo Pan	X			X		X	
Fideos and Candaal Taganrock (Durum)[a]							
Australia:							
Prime hard	X				X	X	
Hard	X				X	X	
Australian Standard White		X			X	X	
Australian Standard White—soft varieties			X		X	X	
Australian Soft			X		X	X	
Durum[a]							
Canada:							
Canadian Western Red Spring	X			X			X
Canadian Prairie Spring		X		X			X
Canadian Utility	X			X			X
Canadian Western Red Winter	X			X		X	
Eastern			X		X		X
Western Amber Durum[a]							
France:							
By lot specifications			X	X	X	X	X
United States:							
Hard Red Spring	X			X		X	
Hard Red Winter	X			X	X		
White wheat					X	X	
Western White			X		X	X	
Western Club			X		X	X	
Soft Red Winter			X	X		X	
Durum[a]							

[a] Durum is a highly specialized wheat type generally not classified with others.

SOURCE: Canada Grains Council, *Wheats of the World* (Winnipeg, MB: 1979).

Table 5-2.—Required Protein Levels for Wheat-Based End Products and Protein Content of U.S. Wheat Classes

Uses		Sources	
Product	Protein content (percent)	Wheat class	Protein content (percent)
Pasta	13 and above	Hard Red Spring	12-18
Hearth bread	13-14	Durum	10-16
Hard rolls	13-14	Hard Red Winter	9-14
Pan bread	11.5-13	Soft Red Winter	8-11
Crackers	10-11	White wheat	7-11
Biscuits	9.0-11.0		
Cake	9-9.5		
Pie crust	8-10		
Cookies	8-9		

SOURCES: S. Evans, "Wheat: Background for 1985 Farm Legislation," Agriculture Information Bulletin No. 467, Economic Research Service, U.S. Department of Agriculture, Washington, DC, 1984; and J. Halverson and L. Zeleny, "Criteria of Wheat Quality," *Wheat Chemistry and Technology*, Y. Pomeranz (ed.) (St. Paul, MN: American Association of Cereal Chemists, 1988).

body the characteristics suitable for the desired end products. Table 5-3 provides a guide to regional tastes and preferences for end products as well as the required flour protein levels and wheat types to produce them. Western White wheat has been the preferred U.S. wheat class imported by Far East Asian countries under Public Law 480, and the region still imports substantial amounts of White wheats from the United States and Australia (4). Besides hav-

Table 5-3.—Regional Tastes, Preferences, and the Requirements for Wheat-Based End Products

Region	Major products consumed	Average required protein level	Types of wheat used
Far East Asia	Pan bread	12-14	Hard Red
	Steamed products	10-11	Medium-hard
	Noodles	9-11.5	Soft to Medium-hard White
	Chappatis	9-10	Soft to Medium-hard White
Middle East and North Africa	Bread		Durum, medium-hard White and Red
	Couscous, Pasta, Bulgur, Fereek	9-11	Durum
Europe	White pan bread	10-12	Hard Red, domestic soft
	Rolls	9.5	
	Pasta		Durum
Latin America	Breads	10-14	Hard Red, domestic soft
	Pasta		Durum

SOURCE: Canada Grains Council, *Wheats of the World* (Winnipeg, MB: 1979).

ing appropriate protein content, White wheats are preferred because they produce products with acceptable color.

Wheat importers in regions of high bread consumption have more than one option for achieving protein levels required based on relative prices and qualities, Government policies, and other factors (4). If there is sufficient domestic production of soft wheat, high-quality wheats can be imported for blending to upgrade the flour. This is customary in the United Kingdom, which imports CWRS and HRS for this purpose. In regions of insufficient or no local production, flour millers can import either moderately high-quality wheat, all of which is the desired protein content, or a combination of hard and soft wheats to blend together to achieve the required protein level. In the Mediterranean region, medium-hard White wheats from the United States and Australia are imported to fill the gap between domestic production and total wheat needs.

The Dynamics of the Wheat Market

International wheat trade has been characterized by change. As a result, there has been no consistent indication by the market of ideal wheat quality. Major importers purchase a variety of classes and grades. Many new importers that have entered the market require different characteristics from the quality bread wheats in high demand during the last two decades. Changes in milling and baking technology have resulted in lower protein requirements, while increased sophistication in milling and baking technology has made knowledge of the specifications of wheat shipments more important. Generally, the required average flour protein differs by country and end product, as indicated in chapter 4.

Developing countries are rapidly becoming the areas of growth in world market demand from a total wheat import perspective. Traditional importers such as Japan and Western Europe have declined in relative importance. This trend is expected to continue as imports by developing countries account for a greater proportion of world trade. Africa and the Middle East have historic wheat consumption growth rates of 8 percent, compared with 3 percent for Japan and 4 percent for the world.

Related to this is the observation by several researchers that wheat product consumption patterns in developing countries differ from the leavened bread orientation of industrial countries. The demand growth in non-bread-consuming countries has switched the emphasis in world trade away from high bread-making quality wheats toward lower priced, lower protein wheats. Technological changes and declining consumption in industrial countries have also aided this shift.

Analysis Results

Many factors influence demand for quality characteristics, as indicated. Relative prices, income, domestic production, and preferences all have an effect.

Relative Prices

One important factor influencing demand for wheats of different qualities is the variability in relative prices. Price differences in international markets were relatively small prior to 1973, probably reflecting the supply/demand situation and the lack of need to distinguish between wheat classes. Since then, differentials have increased dramatically in nearly all markets, indicating the increased differentiation in the international market (2). Notable gaps occurred between the prices of stronger wheat (HRS and CWRS) and all other classes, and the relative increase in CWRS has exceeded that of HRS. Embedded in these prices are implicit values for quality characteristics. Analysis of these values indicates that significant premiums exist for Canadian wheats (or discounts for U.S. wheats), that significant implicit values exist for spring v. winter planted, and that the implicit value of protein has been increasing throughout the 1980s.

Income and Domestic Production

With the importance of developing countries in the growth of the world grain trade, it is essential to examine the role of income in the quality of wheat purchased. In addition, the importance of the level of per capita domestic wheat production is considered. Countries with higher wheat production may have different requirements regarding imported wheat quality than those with little or no domestic production.

Countries representative of wheat producers and importers with different income levels were selected for analysis (table 5-4). Bread prices range from $0.40/kilogram in Pakistan to $1.88/kilogram in Sweden. Per capita consumption for food ranges from 47 kilograms in Brazil to 164 kilograms in Greece, compared with 86 kilograms in the United States.

Previous studies indicate a tendency for high-income countries to use relatively more wheat for feed (5). The logic is that in times of wheat surpluses the price differential between wheat and coarse grains may be reduced to the point

Table 5-4.—Wheat Consumption in Selected Countries, 1984/85

Country	Bread price (cents per kilogram)	Real income (thousand dollars per person)	Wheat consumption (kilogram per person)	
			Total	Food
Importers:				
Austria	61	6.9305	112.848	71.788
Brazil	85	0.0540	47.518	47.518
Denmark	133	7.6354	342.857	92.368
Germany	96	8.7645	157.437	77.738
Greece	52	1.5632	185.930	163.819
Ireland	77	3.1068	210.734	112.994
Japan	151	9.6621	52.216	51.033
Jordan	56	0.9351	117.262	117.262
Netherlands	78	7.2426	132.455	83.911
Norway	173	9.2084	91.787	79.710
Pakistan	40	0.2305	133.247	133.247
South Africa	136	1.4330	69.065	64.025
Spain	49	2.6039	149.702	103.815
Sweden	188	8.0802	102.638	66.307
Switzerland	98	11.5979	121.118	91.149
United Kingdom	53	5.7339	184.422	97.681
Exporters:				
Argentina	41	0.0130	152.824	150.332
Australia	106	7.9079	187.967	146.396
Canada	129	9.7567	207.043	107.561
France	129	6.0351	233.236	113.706
United States	177	12.3430	132.512	85.998

SOURCE: Office of Technology Assessment, 1989.

where feeding wheat becomes economical, and generally only high-income countries can afford to feed large livestock populations. OTA analysis indicates that a significant inverse relationship exists between the proportion of wheat used for food and income. A smaller proportion of wheat is used for food in higher income countries or they use relatively more wheat for feed. Lower income countries, on the other hand, consume a greater proportion of wheat as food.

Table 5-5 shows market shares by class of wheat imported. CWRS, HRS, and EC wheat do relatively well in Western Europe. Correlations between market shares, income, and domestic production were computed (table 5-6). A number of points are clear. First, market shares for stronger, high-protein wheats are positively related with income. Second, market shares of HRW and SRW are inversely related to per capita income. Third, domestic wheat production is inversely related to HRW and Argentine shares, but positively related to the CWRS market share. These results suggest that income level and domestic production influence wheat import patterns. Countries with relatively large domestic per capita production have a tendency to import a greater proportion of Canadian wheat and less Argentine and HRW. Lower income countries tend to purchase the less expensive wheats, possibly due to reduced ability to pay or because they do not require the characteristics of stronger wheats. The level of domestic wheat production affects wheat class market shares, likely reflecting blending v. filler wheat requirements. Thus, the tendency is a shift to CWRS by countries with higher levels of domestic production and a shift away from HRW.

Preferences

Considerable variation exists among markets in the wheat classes imported, their relative importance, and historic growth rates. Useful information can, therefore, be gained by analyzing class or quality import demand on a market-by-market basis. Such an analysis, as previously noted, shows that relative prices and income are significant determinants of market shares. In addition, however, it indicates that a different preference structure exists for individual wheat classes.

The most prominent shifts are away from the dominant HRW and toward weaker wheats (EC and SRW) or stronger wheats (HRS, CWRS, and Durum) (table 5-7). In the overall world trade market, preferences shifted from HRW and toward all other classes. Results from most regional markets are similar. Growing nonprice preferences for SRW, HRS, and CWRS exist in Asia. SRW and Durums are gaining preference in Africa relative to HRW. In Japan, HRW is losing preference to White and HRS. In addi-

Table 5-5.—Market Shares of Imported Wheat Classes, 1984/85

Country	Argentina (ARG)	Australia (ASW)	Canada (CWRS)	European Community (EC)	U.S.				
					HRS	HRW	SRW	White	Durum
Brazil	0.15	0.00	0.27	0.01	0.00	0.54	0.01	0.00	0.00
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
France	0.00	0.00	0.73	0.00	0.02	0.00	0.00	0.00	0.23
Germany	0.00	0.00	0.66	0.00	0.33	0.00	0.00	0.00	0.00
Greece	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Japan	0.00	0.17	0.23	0.00	0.17	0.22	0.00	0.18	0.00
Jordan	0.13	0.15	0.00	0.01	0.00	0.69	0.00	0.00	0.00
Netherlands	0.04	0.00	0.10	0.00	0.69	0.00	0.01	0.00	0.14
Norway	0.27	0.00	0.53	0.19	0.00	0.00	0.00	0.00	0.00
Pakistan	0.02	0.60	0.00	0.14	0.00	0.00	0.04	0.17	0.00
South Africa	0.03	0.93	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Spain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sweden	0.00	0.00	0.60	0.40	0.00	0.00	0.00	0.00	0.00
Switzerland	0.00	0.00	0.36	0.63	0.00	0.00	0.00	0.00	0.00
United Kingdom	0.00	0.00	0.93	0.00	0.06	0.00	0.00	0.00	0.00

SOURCE: Office of Technology Assessment, 1989.

Table 5-6.—Correlation of Imported Wheat Class Market Shares, Income, and Domestic Wheat Production, 1984/85

Market shares	Australia (ASW)	Canada (CWRS)	European countries (EC)	Argentina (ARG)	United States					Income	Domestic wheat production
					HRS	HRW	SRW	White	Durum		
Australia	−1.0	—	—	—	—	—	—	—	—	—	—
Canada	−0.52[a]	−1.0	—	—	—	—	—	—	—	—	—
European Community	−0.18	−0.29	−1.0	—	—	—	—	—	—	—	—
Argentina	−0.04	−0.22	−0.14	−1.0	—	—	—	—	—	—	—
U.S. HRS	−0.18	−0.13	−0.26	−0.12	1.0	—	—	—	—	—	—
HRW	−0.02	−0.38	−0.24	−0.44[a]	−0.15	1.0	—	—	—	—	—
SRW	0.39	−0.38	−0.09	0.08	0.01	0.05	1.0	—	—	—	—
White	0.38	−0.33	−0.11	−0.15		0.03[a]	0.58[a]	1.0	—	—	—
Durum	−0.18	0.07	−0.21	−0.14	0.38	−0.17	−0.04	−0.14	1.0	—	—
Income	−0.44[a]	0.34	0.13	−0.13	0.31	−0.42	−0.46[a]	−0.03	0.11	1.0	—
Domestic Wheat Production	−0.27	0.69[a]	−0.12	−0.47[a]	−0.16	−0.45[a]	−0.19	−0.25	0.22[a]	0.11	1.0

[a] Indicates significance at the 10-percent level.

SOURCE: Office of Technology Assessment, 1989.

Table 5-7.—Average Growth Rates[a] of Wheat Class Imports by Country, Region, and World, 1961/62-84/85 (percent)

Country/region	United States							Canada			Total	
	HRS	HRW	SRW	WHI	DUR	ARG	ASW	CWRS	CAD	EC	imports	Consumption
Africa	—	5.2	13.0	—	19.1	—	—	2.9	33.1	9.8	8.9	—
Asia	9.2	−3.3	34.8	3.0	—	5.9	1.1	2.8	—	3.6	2.4	—
Japan	24.6[b]	3.6	—	2.8	—	—	4.3	0.20	—	—	3.3	—
Latin American	7.5	6.0	5.7	−0.3	17.2	−1.1	—	7.6	—	3.2	5.1	—
Middle East	—	3.2	9.2	18.1	—	—	12.9	15.2	—	10.6	9.5	—
United States	1.4	2.4	1.9	2.1	2.6	—	—	—	—	—	—	2.1
World	8.5	3.0	8.6	3.6	—	4.3	3.3	2.7	—	6.0	4.0	—

[a] Derived from a simple regression of $\log Q_i = y + B \bullet T$ using autoregression techniques. Q_i is annual imports of Class i, T is time trend, and B is the growth rate and the reported coefficient.

[b] This figure is relatively high because in early years HRS imports were nil.

SOURCE: Office of Technology Assessment, 1989.

tion, CWRS, though preferred, is losing relative to White and HRS. But the Latin American market has a strong preference for HRW. Similarly, there are strong and relatively stable preferences for HRW in U.S. domestic markets.

Simulations of changes in wheat class market shares that extrapolate historical preference changes identify important changes (table 5-8). The important underlying assumption is that of constant relative prices. The SRW share of the Asia market is expected to grow by 14 percent by 1995 with losses between 2 and 5 percentage points for most other competitors. In Japan, the HRS share increases by 5 percent. HRW consistently loses between 2 and 4 percent in all regional import markets except Latin America.

Case Study Summary

The analysis measured and compared underlying nonprice shifts in preferences occurring through time. Several regional shifts of particular interest include:

- increases in SRW, HRS, and CWRS in Asia;
- increases in SRW and Durum in Africa, and decreases in HRW;
- decreases in HRW in the Middle East; and
- decreases in SRW in Latin America and increases in HRW and spring wheats.

In general, the world market is experiencing nonprice shifts in preferences away from HRW and toward soft wheats (SRW and EC) and HRS.

Numerous changes in market shares of wheat classes are expected in specific markets, and in some cases these are relatively large. In general, these changes reflect the shifts in preferences. However, despite the shift in preferences toward HRS, growth in this market will be stalled due to the current high price for this class relative to others.

In general, the results indicate that quality differentials are important in international markets, affecting both relative prices and shares in particular markets. Given the unique demands for different classes of wheat and the key underlying shifts in imports, the ability to differentiate wheats of different classes is an important component of international competition. A particular concern, however, is that in many markets the preferences for U.S. wheats are distinctly different from like wheats of competitors. In some markets, imports tend to shift toward stronger wheats as income increases. This is not generally true, however, and in fact in some cases higher incomes through time result in more imports of softer wheats. Thus, strong wheats are not necessarily a luxury, and softer wheats are not necessarily inferior.

Table 5-8.—Simulated Changes in Wheat Class Market Shares, 1985/95 (percent)

Region Class:	HRW	SRW	WHI	EC	ASW	ARG	HRS	CWRS	DUR	CDUR
Africa:										
1984 share	14.5	19.9	—	46.6	—	—	—	5.0	9.6	4.4
1985-95 change	−3.1	1.6	—	−0.8	—	—	—	−0.8	0.1	3.0
Asia:										
1984 share	7.2	18.3	19.1	—	28.5	—	7.5	19.3	—	—
1985-95 change	−4.0	14.3	−3.4	—	−4.3	—	−0.5	−2.3	—	—
Japan:										
1984 share	22.9	—	17.1	—	18.4	—	18.1	23.4	—	—
1985-95 change	−2.0	—	−0.7	—	−0.1	—	5.1	−2.5	—	—
Latin America:										
1984 share	48.0	5.4	1.5	2.4	—	13.0	11.5	15.5	2.7	—
1985-95 change	0.5	−0.2	−0.1	−0.2	—	−2.4	0.6	1.0	0.8	—
Middle East:										
1984 share	12.0	3.4	9.3	21.9	42.8	—	—	10.7	—	—
1985-95 change	−2.5	−0.3	0.8	0.6	0.8	—	—	0.6	—	—
United States:										
1984 share	48.7	25.0	7.5	—	—	—	15.1	—	3.8	—
1985-95 change	−1.0	0.0	0.6	—	—	—	0.2	—	0.1	—
World:										
1984 share	19.1	7.1	6.0	18.2	15.9	8.4	5.1	20.2	—	—
1985-95 change	−1.3	1.7	−0.1	0.5	−0.4	−0.1	0.6	−0.9	—	—

SOURCE: Office of Technology Assessment, 1989.

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Chapter 6

The Genetics of Grain Quality

The most fundamental starting point for efforts to improve the United States' ability to produce, handle, and deliver quality grain is the seed. The role of plant genetics cannot be overstated. Indeed, if the genes for physical and intrinsic quality are not present, little can be done in the rest of the system to improve quality.

Quality is influenced by plant genotype and the environment in which the plant is grown. Genotypes often can be altered using classical plant breeding methods so that changes in quality result. This has not generally been the aim of breeders, however, as their focus on increased yield often means quality factors such as protein or oil content remain the same or even decline unless special incentives are present for the grower. Likewise, some environmental factors can be changed, such as soil fertility through fertilizer application or water status through irrigation. Many others, however, cannot be affected, such as weather and soil type.

Plant breeding can offer a partial solution to problems caused by environmental variation, through consideration of genotype-environment interactions. This chapter considers for wheat, soybeans, and corn:

- the objectives of genetic selection;
- direct genotypic influences on physical and intrinsic quality and the interactions between genotype and environment that affect seed quality;
- the procedures, tests, and criteria for releasing seed varieties; and
- emerging plant breeding technologies to improve quality.

WHEAT

The wheat plant and the grain it bears have evolved over many centuries into the plants grown today. Early humans over thousands of years selected types of wheat with the largest seeds, leading to the wheat grown in crop agriculture in Europe and Asia prior to migration of people to North America in the early 17th century. Early North American immigrants brought wheat seed with them that had been selected from variable native species with different characteristics that were used to make different foods. This led to the different classes of wheat with different end uses now grown in the United States.

Differentiation of end-use characteristics of these different wheats is important. Because the science of wheat breeding has many common points across wheat classes, however, this section is organized by topic area. Any important differences by class will be highlighted in the discussion.[1]

Objectives of Genetic Selection

Wheat breeders have two major objectives: to raise yield and to increase end-use quality. A secondary objective is to improve resistance to diseases, pest, and environmental stress. Reaching these goals is difficult. High yields are an important attribute that farmers demand in a new variety. On the other hand, millers desire wheat with good end-use characteristics, such as high protein content. Yet an inverse genetic relationship exists between yield and protein content in wheat.

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[1] This section is based on Jack F. Carter et al., "Wheat Breeding Issues Related to Grain Quality," prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

The primary goal of wheat breeders is usually increased yield, with protein and other end-use quality factors maintained at acceptable levels. Table 6-1 illustrates this point with new Hard Red Spring (HRS) varieties produced in North Dakota and tested from 1981 to 1985. Waldron is the check or control variety, and each new variety exceeded Waldron in yield by 6 to 15 percent. To achieve higher yield, however, protein percentage decreased by as much as 0.5 percent on average. Other selected end-use quality factors stayed about the same or declined compared with the check variety.

This is not to suggest that improvements in certain quality have not been made. In Hard Red Winter (HRW) wheat, traits that have significantly improved include test weight, flour yield, mixing time, loaf volume, and crumb grain. But protein percentage has remained essentially constant (16). In HRS and Durum, the same characteristics have improved.

Genetic Influences on Wheat Quality

Table 6-2 lists important end-use quality traits, the estimated number of genes thought to control a trait, and the degree a trait is influenced by the environment. Environmental variation influences the expression of all heritable traits. Those whose expressions are largely influenced by the environment have low heritabilities, i.e., the majority of the variability for that specific trait is due primarily to the environment and not to the genotype.

Functional quality is the interaction of all the traits in table 6-2 plus others. It is impossible to select one trait individually and interpret end-use quality. Final bread-making quality is the total interaction of all these traits (23). Cereal chemists and wheat breeders use these traits to estimate end use. If all the traits fall into identified accepted categories, the final product is usually satisfactory.

Yield-Quality-Resistance Interactions

Grain yield, grain quality, and disease resistance cannot be separated in a wheat breeding program. Each fits into a package that is released as a new variety. Wheat lines are not developed that feature improvements in some traits and the loss of others. Wheat diseases, lodging, and environmental stress produce shriveled grain that reduces grain yield, lowers test weight, and decreases flour milling yield. However, the best bread-quality wheat is not grown by farmers unless it yields competitively. As noted, yield and quality if evaluated sep-

Table 6-1.—Grain Yield and End-Use Quality Characteristics of Four Wheat Varieties in North Dakota, 1981-85 Average

	Location						
Cultivar	Dickinson	Williston	Minot	Carrington	Langdon	Fargo	Mean
Grain yield—percent of WALDRON:							
LEN	109	101	104	96	117	108	106
ALEX	109	105	106	105	113	110	108
STOA	124	107	108	107	120	120	115
Wheat protein content—percent (14.0% M.B.):							
WALDRON	15.9	17.7	14.8	16.6	14.8	15.3	15.9
LEN	15.3	17.2	15.0	16.6	14.6	14.8	15.6
ALEX	14.6	17.7	15.2	16.5	14.6	14.8	15.6
STOA	14.4	17.4	14.8	16.6	14.6	14.6	15.4

Cultivar	Test weight (lb/bu)	Vitreous kernels (percent)	Flour extraction (percent)	Wet gluten (percent)	Flour ash (percent)
Quality comparisons:					
WALDRON	58.0	83	67.6	40.2	0.47
LEN	59.1	85	68.5	38.1	0.47
ALEX	60.3	86	66.8	39.9	0.45
STOA	59.2	84	68.0	39.2	0.42

SOURCE: Richard Frohberg, "Wheat Breeding at North Dakota State University," presented at U.S. Wheat End-Use Quality Conference, Fargo, ND 1986.

Table 6-2.—Environmental Influence on Important End-Use Quality Traits in Wheat

Trait	No. of genes	Environmental influence
Physical quality:		
Hardness	3 genes	moderate
Color	3 genes	moderate
Kernel size	many	large
Test weight	many	large
Flour yield	many	large
Biochemical quality:		
Protein percentage	few-many	large
Absorption	many	moderate
Mixing tolerance	many	large
Loaf volume	many	large
Crumb grain	many	large
Crumb color	many	moderate
Loaf symmetry	many	moderate
Gluten strength	few	moderate
Pasta quality	many	large

SOURCE: Office of Technology Assessment, 1989.

arately as unique entities are usually negatively correlated, primarily due to the negative association between protein percentage and grain yield (35). This negative correlation in soft wheats is extremely beneficial as it allows for concurrent progress in these traits. Low protein percentage is a requirement for producing high-quality end products from soft wheat.

Genotypic Variability

Genotypic variability is generally interpreted as the range of expression for a specific trait, i.e., protein percentage can range from 7 to 30 in wheat. Wheat has not been investigated adequately to determine the range of available genetic variation and to identify the appropriate breeding procedure for each of the characters controlling quality. Wheat germplasm collections have been evaluated primarily for agronomic characters, not for those controlling quality.

Wheat is a hexaploid species and has a large amount of genetic variability. Protein percentage is probably the most frequent quality component measured, and it can be improved by crossing with distant relatives of wheat. A practical limit exists, however, because twice as much energy is required to produce a gram of protein as a gram of carbohydrate (42). In the future, as more is understood about protein quality, it may be more efficient to allow the Hard Red Winter wheat plant produce primarily starch, and then to blend in protein to increase its percentage in wheat flour. The primary use of the genetic variability in wheat in the short term (especially in HRW programs) is to introduce new genes to protect plant health.

Genotype v. Environment

Genetic variations, environment, and the interaction of these components affect the final expression of a trait. Genetic-environmental interaction is produced when different genotypes respond differently to different environments. The HRW variety Newton, for example, produces acceptable quality in western Kansas, but is poorer in eastern Kansas due to disease, in Oklahoma because of late maturity, and in eastern Colorado because of susceptibility to root rot. Environment can be more responsible, in many cases, than the varietal reactions for increased fluctuations in quality (34,41). Genotype-environment interaction is of crucial importance because most HRW wheat varieties are grown across a diversity of environments, and stable quality performance is desired. In addition, more extensive testing programs are required to identify stable genotypes.

Interactions between physical and biochemical characters are frequent, and usually negative. The most noted association involves protein, as discussed earlier. This makes it difficult to improve both traits. However, protein percentage and protein quality are not correlated (23). It is possible to have extremely high protein and very low protein quality. The HRW wheat variety Atlas is a good example. Other interactions that affect progress in a breeding program include kernel size and flour yield, high temperatures at grain filling, and weaker mixing tolerance. Susceptibility to diseases and preharvest sprouting have negative effects on quality. Associations between chromosomes themselves affect quality. For example, attempts to breed resistance for wheat streak mosaic virus have been unsuccessful because the resistant genes for the disease are closely linked to genes that have a negative effect on quality (38).

Role of Public and Private Wheat Breeders

Public and private wheat breeders develop and prepare release of new wheat varieties. One main difference is that public breeders generally work with wheat only for the State or regions within it where they are employed, whereas private breeders develop wheat varieties for one or more States plus foreign countries where the company may have a subsidiary. Another difference is that private breeders can respond more quickly to sudden needs or perceived opportunities for research and development.

One point currently under debate is whether public breeders should only develop basic germplasm and let private breeders use the germplasm to develop the varieties for commercial sale—a system more or less followed in Europe. An argument can be made for such a role differentiation. As the next section points out, however, currently the return on investment in developing new wheat varieties has resulted in many seed firms eliminating wheat breeding from their research activities.

Public funding of wheat plant breeding is derived (in order of importance) from State legislatures, Congress, farm commodity organizations, and foundation seed royalties. Funding is often closely related to the economic health of the State. Overall, funding was relatively stable from 1950 to 1980, but it has declined in real terms since then. State Agricultural Experiment Station (SAES) funding for wheat breeding programs can vary from 35 to 75 percent of the total SAES budget. Some States have begun charging royalties on seed of new varieties in order to help fund plant breeding research as competition increases for use of limited public funds.

Private funding for wheat improvement research is corporate funding to produce a product for sale and, it is hoped, a high return on investment. The financial support and resources may be more generous relative to public funding, but they can be decreased or terminated quickly if return on investment is inadequate. For example, many large and small seed companies initiated breeding programs soon after the passage of the Plant Variety Protection Act in 1970. Wheat breeding did not produce high rates of return for most, however; and today only a few large firms have programs on conventional wheat varieties and/or hybrid wheat. Thus most new wheat varieties are developed by the public sector.

Variety Release Procedures

Public and private wheat breeders attempt to create varieties excelling in both agronomic and end-use characteristics. The public breeder, who produces most of the new varieties, receives guidance on criteria for release from the individual State Agricultural Experiment Stations. In turn, the SAES bases its recommendations on the national policy on release of seed-propagated plants adopted by the Experiment Station Committee on Policy. However, the policy is *guidance only* and States may and do vary from it. Private wheat breeders are influenced by the principles of this policy as well and by the demands or needs of farmers.

The principles used to determine whether to release superior experimental genotypes are based on whether the candidate for release is better in one or more agronomic or quality characteristics as compared with "check" or "control" commercial varieties. But market incentives to farmers and in turn to the wheat breeder signal advancement and release of experimental progenies having unusually high grain yield and not necessarily meeting minimum standards of other agronomic and end-use characteristics. The market seldom rewards farmers who produce wheat varieties with excellent end-use characteristics.

Public Breeder

The general procedures used to select a variety for release are as follows:

- The plant breeder makes crosses of desired parents and progenies and evaluates them over 5 to 8 years for agronomic and end-use characteristics. Those characteristics are compared with a "standard check" or "control" variety, usually a commercial variety under production over a significant acreage in the target geographic area.

- The breeder evaluates and justifies the release and name of the experimental progeny.
- A Variety Release Committee (VRC) of scientists of the wheat breeding team, appropriate extension specialists, representatives from appropriate commodity and regulatory agencies, and the Experiment Station Director recommends release or rejection of the experimental line proposed for release.
- If the VRC cannot agree, the final decision is made by the Director of the Experiment Station.
- The agricultural experiment station is usually considered the "breeder of record" for purpose of Plant Variety Protection and royalties.
- Basic seed stocks of the new variety are increased to Foundation seed by SAES or a quasi-nonprofit agency for the public variety.
- Elite growers increase the new variety to Registered and Certified seed for use by commercial growers.
- The breeder deposits a small amount of breeders' seed in the Germplasm Bank at the National Seed Storage Laboratory.

Private Breeder

Based on mail inquiries to private breeders, the policies and procedures on variety development and release seem to be as follows:

- The wheat breeder makes hybrids of desired parents and progenies are evaluated for various agronomic and end-use characteristics. Most of the hundreds of progenies from the original "cross" of the two parents are discarded at each testing stage, but a few superior ones are selected and advanced after several generations as worthy of further evaluation.
- A preliminary test is conducted of apparently superior wheat progeny lines at several locations, for 1 year, and each entry is evaluated for agronomic and end-use characteristics. Many wheat lines are discarded as not worthy of further testing.
- An advanced test is conducted at additional locations, again for 1 year, with continued evaluation and further discard of some lines and retention of the most superior ones.
- Elite testing is conducted at even more locations for 2 years with continued agronomic and end-use quality evaluation at the private company quality laboratory and at independent quality laboratories. The latter might include Class end-use quality laboratories, private or public agencies, or a cooperative facility with the milling industry (e.g., flour and bread evaluation by the Spring Wheat Quality Advisory Committee (SWQAC)).
- Wheat progenies (lines) excelling in the elite testing receive Precommercial Nomination based on 2 years of testing and satisfactory end-use quality scores. A Committee or Director of Research, Crop Director, Cereal Chemist, Breeder(s), and Crop Marketing Analyst accepts the variety as *precommercial* if all agronomic, disease, and quality end-use data are satisfactory.
- A third year of elite testing is conducted, including evaluation by an independent agency such as SWQAC. Breeders seed is produced to continue seed increase advancement, if approved.
- The same Committee that considered precommercial status evaluates again and, if approved, Foundation seed is produced and sales divisions are notified. The Plant Breeding Division retains control of the prospective variety. If release is approved, seed is distributed to sales divisions for registered and certified seed production. The Director of Plant Breeding and the Crop Director sign the official release announcement.
- A Commercial Number (equivalent to variety name) is assigned. Seed is conditioned at company plants and allocated to District Sales Managers who establish sales goals

for each sales area. Farmer-dealers sell the seed. The company provides advertising support.

Wheat Breeding Technology

U.S. public and private wheat breeding programs annually release several dozen wheat varieties, each representing 8 to 15 years of research. The principal wheat-producing States have had wheat improvement programs for at least 60 years, and their accomplishments have been impressive. U.S. wheat yields since 1958 rose from 25.1 to 33.1 bushels/acre, a 32-percent increase. Comparisons from regional nurseries indicate a 17-percent genetic gain, accounting for about half the total yield or 0.2 bushels/year genetic gain (46). Production technologies—including use of fertilizers, herbicides, pesticides, and machinery—accounted for the other half of the yield increases.

This section provides a general perspective of wheat breeding by describing some of the capabilities, methodologies, and limitations of current and future technologies.

The Breeding Program

Generalizing about procedures is difficult because there are as many permutations and combinations of managing the logistics of selection and testing as there are programs. Nevertheless, some primary features of wheat breeding can be described by considering the basic framework of generational advance and testing (table 6-3).

The genetic variation to begin the breeding cycle is obtained through sexual recombination in F_1 plants from 200 to 700 crosses per year. Segregated populations of tens of thousands of F_2 plants, each one a new and distinctive genotype, are grown each year. Genetic segregation continues in the F_3, F_4, and successive self-pollinating generations, diminishing by half each generation as the genotypes of lines become fixed.

In early generations, selection is based on traits that are recognized visually or otherwise evaluated easily, such as plant maturity, plant height, stem and leaf rust resistance, and general plant appearance. Such selection is considered fairly subjective.

Table 6-3.—Generational Advance in a Typical Pedigree Wheat Breeding Program

Season	Generation[a]	Breeding population size	Selection/evaluation activities
1	Initial crosses	200 to 700 new crosses per year	Some selection among F_1s based on additional data or phenotype
2	F_1	200 to 700	
3	F_2	500 to 2,000 plants per F_2 population	Grown as spaced plants, sometimes as bulk populations. Strong selection between populations and for plants within populations, visual selection for easily classified traits
4	F_3	5,000 to 50,000 total plant or head rows	Begin line selection, visual selection, visual selection for easily classified traits, e.g., height, rust resistance
5	F_4	1,000 to 5,000 observation rows or head rows	Continue visual selection with additional traits, possibly begin protein, few quality evaluations
6	F_5	400 to 1,000 lines in preliminary yield trials or observation rows	Testing becomes more quantitative, replicated, multi-location, initial yield data, quality evaluations
7	F_6	150 to 400 lines in yield trials	Similar to F_5
8	F_7	20 to 50 lines in advanced yield trials	Yield trials at several locations, complete quality and disease resistance testing
9-11	F_8	5 to 10 elite lines	Extensive yield testing in State and regional trials, complete disease and quality comparisons to standard varieties, identification of candidate varieties

Finally, seed increase decisions are made during final evaluation stages and at the time of varietal release.

[a] Filial generation.

SOURCE: Office of Technology Assessment, 1989.

Selection for each trait further depends on the time required to measure the trait, the number of plots that must be evaluated to obtain a reliable estimate of the line's performance, the amount of seed required for the test, and the effect of environment on other traits being selected.

Selection for quality in early generations and during preliminary testing is accomplished mainly by using micro-evaluation procedures. Cereal chemists and breeders have devised an array of such tests that correlate with functional processing quality. Mixograms, cookie tests, and micro-loaves are examples of tests that can be done using small samples of wheat kernels.

Improving the Efficiency of Wheat Breeding

Each breeding program strives to improve the efficiency of its selection and testing procedures and to understand the available genetic variation. The dynamics involve a steady flow of information and data from many sources. Crossing, selection, and testing decisions are revised as agronomic, disease, and quality data from the current season's nurseries, and area wheat crop are evaluated.

Experimental design, statistical analyses of data, and plot and testing equipment are refined continually. Breeding programs collect enormous amounts of data each year. Much of the analysis that formerly was done with mainframe computers now is being done with microcomputers. Also, computer programs are being written that greatly facilitate various organization and data collection activities of the breeding program.

The impact that a new analytical technique can have on selection strategy is shown vividly by the application of near-infrared reflectance spectroscopy (NIRS) to measure protein and moisture percentages. NIRS, developed in the 1970s, is rapid, practical, and inexpensive. Protein percentage can be determined on about 200 wheat or flour samples per day with a single NIRS machine. For a wheat breeding program, this means that early generation selection for protein percentage can become routine, substantially increasing the proportion of later generation lines that have the desired protein level.

Replicated yield trials are expensive to conduct. A breeding program must grow several thousand yield plots each year at several locations. In recent years, small-plot combines have been developed in which one to two yield plots per minute can be harvested while maintaining seed integrity of each plot.

Other Quality Considerations

Wheat breeders encounter several breeding situations in which quality can become a problem. The most common one occurs when selection for one trait causes changes in another trait or traits. The correlated response can be positive or negative, and the degree can vary from slight to very strong. For example, the gene in Durum wheat for white glumes and the gene for strong gluten strength are located near one another on the same chromosome. Durum breeders have used this fortuitous association effectively to identify strong gluten Durum lines. In bread wheats, the negative correlation between grain yield and protein percentage that exists in many breeding populations challenges the breeder to find genes that increase protein percentage or improve the quality of the protein without losing yield potential.

Other situations in which quality can be affected adversely involve the introduction of genes from related species. The best known example is the IB/IR wheat-rye chromosome translocation. The rye chromosome introduced into wheat carries valuable genes for disease resistance, but it also can cause problems with stickiness of bread dough. Problems with test weight, flour color, and other traits have been associated with an alien chromosome segment introduced for disease resistance in several other cases.

Timetable of Wheat Breeding and Varietal Seed Increase

Evaluating past progress in wheat breeding, planning future research, and having some idea about the possible rates of progress of future research requires an appreciation of the time required for varietal development, testing, and seed increase. The breeding and seed increase schedule for Stoa, an HRS wheat variety recently released by the North Dakota Agricultural Experiment Station, provides an example (table 6-4). Greenhouses, off-season winter nurseries, and early, coordinated increases of seed can accelerate this schedule. But it is important to remember that crosses for wheat varieties for the year 2000 are being made now, 12 years before they will be released.

Some future technologies may shorten the period for varietal development far less than intuitively might be expected. Much of the schedule for Stoa is devoted to the initial buildup of seed, to multiyear testing, and to increasing the varietal seed. This process must be done regardless of how a line was produced initially.

Hybrid Wheat

Much progress has been made during the past 25 years to develop germplasm and techniques for commercial production of hybrid wheats. A hybrid advantage for grain yield and other traits similar to those found in corn, sorghum, rice, and other crops is the impetus for hybrid wheat research. Because the farmer must purchase hybrid seed each year—unlike varietal seed, which can be grown from the previous year's seed—the successful development of hybrid wheats also would be the basis for a large commercial seed industry in the United States. Several commercial seed and agricultural chemical companies have hybrid wheat research efforts.

Two technologies are being used for hybrid wheat development:

1. genetic systems that use a cytoplasmic male-sterile female parent and a fertility restorer male parent for hybrid seed production, and
2. chemical systems that use chemical hybridizing agents to treat and sterilize the female parent for production of hybrid seed by cross-pollination with the male parent.

Commercial hybrids have been produced and marketed using both types of systems.

Current hybrid wheat research aims to improve hybrid performance and to reduce the costs of producing hybrid seed commercially. The economic success of hybrid wheat will be determined by the hybrid breeder's and seed producer's success in accomplishing these goals.

Table 6-4.—Breeding and Seed Increase History for Stoa Hard Red Spring Wheat

Year	Season	Generation	Explanation of evaluation state
1973	Fall	Cross	ND527/Coteau sib//Era
1974	Spring	F_1	Grown in greenhouse
1974	Summer	F_2	Space-planted populations
1975	Summer	F_3	Head-row
1976	Summer	F_3	F_2-derived head-row
1977	Summer	F_5	1 row selected, F_4 derived line
1978	Summer	F_6	Preliminary evaluation
1979	Summer	F_7	Preliminary yield trial
1980	Summer	F_8	Elite yield trial
1981-82	Summer		ND HRS variety trial (tested as ND582)
1982-83	Summer		HRS Uniform Regional Nursery
1983	Summer		Spring Wheat Quality Advisory Committee Test
1984			Named and released
Seed increase (concurrent):			
1981-82	Purification head rows near Yuma, Arizona		
1982	Increase at North Central Station, Minot, North Dakota, 1½ acres		
1982-83	Winter increase near Yuma, Arizona		
1983	Increased in North Dakota		
1984	Released as a variety		
1985	26,000 acres certified plus noncertified acres		
1986	Estimated acreage, 1½ to 2 million acres		

SOURCE: Office of Technology Assessment, 1989.

Quality standards and questions for hybrids in general are identical to those for conventional varieties. The end-use quality of hybrids has tended to be between their two parents for most traits. Some quality control can be achieved in hybrids by choosing parents that have complementary quality traits.

As wheat hybrids must have a yield advantage to be economical, the breeder must be concerned about grain yield/protein percentage relationships in the wheat classes where high protein is desirable. Also, seed produced on a hybrid (F_1) plant differs from seed produced on a variety. The (F_2) seeds are segregating, each genetically different from another. All seed in conventional varieties is genetically homozygous and is homogeneous. Although these effects have not been examined in detail, generally the maternal F_1 plant of uniform genotype seems to have the predominant effect on endosperm quality and on kernel characteristics.

Future Technologies

Genetic Engineering.—Advances in several technologies for genetic manipulation of plant cells and genes, collectively termed biotechnology, have generated much discussion about their application to important plant breeding problems. The new technology having the greatest potential for expanding the genetic variation available to plant breeders is genetic engineering. This term covers the technology or group of technologies with which scientists can isolate genes from one organism, manipulate them in the laboratory, and then insert them stably into another organism. (This stable insertion is known as transformation.) These complex technologies are the focus of extensive, very active research efforts (15,24,45).

The current capabilities of scientists to use genetic engineering in wheat and most major crop plants are limited. These limitations regarding wheat quality include:

1. insufficient knowledge of which genes affect quality;
2. great difficulty in isolating such genes, even if they are known;
3. inability to insert specific genes stably into the host genome; and
4. and lack of knowledge on how to regulate the expression of inserted genes in the target tissue.

While some of these limitations are likely to have technical solutions in the near future, others could remain barriers to using these techniques in wheat breeding for some time.

Once specific favorable alleles of genes that code for glutenin or gliadin proteins are identified, a process that could require a great deal of research, the isolation of these genes could become fairly routine. Current research indicates that many wheat seed storage proteins actually are "families" of proteins (many similar but slightly different proteins) coded by "families" of genes.

Genetic engineering also can isolate seed storage protein genes from other crops. The potential value of these proteins either to improve wheat quality or to impart additional processing attributes to wheat cannot be assessed until such genes actually are inserted into wheat and expressed in the seed.

Currently, there are no reports that cultivated wheats have been transformed and a plant regenerated (15). Genes have been inserted into the cells of a wild relative of wheat (*Triticum monococcum* L.), but no plant was regenerated because of an inability to regenerate plants from single cells, which requires an effective tissue culture system. Although Schell (45) has reported that DNA is taken up and is expressed transiently in wheat embryos, he has not determined if this DNA is transmitted to the offspring—i.e., is heritable.

A prudent estimate is that appropriate techniques to engineer wheat genes will be developed within the next 5 years, assuming adequate resources for experimentation. How effective or efficient these systems will be is difficult to predict.

An example of a technology that must be developed when wheat plants are transformed successfully is the regulation of the expression of genes for defined qualities. The genes must be expressed in the seed but not in other tissues. Experience with other crops suggests that the regulatory sequences for wheat seed proteins will have many of the necessary characteristics of regulating the added new genes (45). Genetic engineering allows the addition of relatively few genes, not a gene family. Because gene families for quality characteristics are expressed in the seed, the added genes may need to be strongly expressed, assuming they affect quality positively.

If detrimental proteins (e.g., the secalin proteins of the IB/IR rye translocation) are operative, these families of genes may need to be turned off, requiring techniques not now known. However, germplasm may be found with suitable analytical tools, either through natural variation or through chromosomal manipulation, that lacks the detrimental family of genes.

It must be restated, however, that until useful genes can be successfully identified, isolated, stably integrated into the wheat genome, and sexually transmitted to offspring, genetic engineering of wheat remains a promise and a goal rather than a useful tool.

If procedures that allow routine genetic transformation of wheat should become available within 5 years, how long would it take for the new technologies to have a major effect on wheat quality? Research to improve understanding of wheat proteins and the specific genes that code for them, including methods to isolate these genes, will proceed concurrently with research on genetic transformation. Manipulating gene regulation fully in seeds will take many years. Transformed plants must be grown to maturity to test seed for gene expression. Small-scale baking quality tests to determine if wheat quality has indeed been improved requires 300 grams (0.7 pounds) of seed. Advanced hard wheat quality evaluations can require up to 550 kilograms (1,200 pounds) of seed.

The first U.S. field tests of transformed plants (mainly tomato and tobacco) were allowed in 1987. Hence, little or no previous knowledge and experience exists on which to base speculations about the agronomic and quality performance of transformed wheat. Assuming the new transformed wheat has excellent quality and agronomic performance, another year or two of seed increase would be needed before sufficient foundation seed could be sold to certified growers who, in turn, must grow the seed for 1 year before they can sell certified seed to the wheat grower. The first genetically engineered seed will enter the commercial market after the following growing season (an additional year), when the wheat grower harvests the crop. Commercial acceptance and use of the new, genetically transformed variety then can be determined.

Consequently, at least 7 years will be required, under favorable circumstances, for a seed of a genetically transformed variety to reach the commercial market—plus possibly another 5 years to develop the transformation technology. Although this seems a long time, the total time from identification of beneficial genes to new plant introduction may be cut by 4 to 6 years.

ELISA and DNA-Probe Screening Assays.—After proteins and genes that enhance or lessen wheat quality have been identified, rapid assays using antibodies or nucleic acids can be used to identify lines having these genes. An example of this technology is the enzyme-linked immunosorbent assay (ELISA), which uses antibodies to identify proteins rapidly. ELISA technology employs a "capture" antibody that is attached to a solid surface and that specifically binds to a single protein from a complex protein mixture. This protein-antibody complex is incubated with an enzyme-coupled antibody that recognizes and binds to the protein. In the presence of a colorless substrate, the enzyme will convert the substrate to a colored product that can be measured spectrophotometrically. The presence of color, therefore, identifies the presence of the (specific) protein that is bound to the capture antibody and to the enzyme-coupled antibody.

ELISA tests are used routinely to identify proteins associated with seed storage proteins and with plant pathogens (as a diagnostic test for diseased plants). Using ELISA techniques to identify specific seed quality proteins is difficult because these occur as families of similar proteins. Isolating specific proteins and obtaining precise antibodies can be difficult. Once the technique is optimized, however, selection to save lines with favorable quality proteins and to discard those with unfavorable ones will be straightforward.

The ELISA technology is not used widely yet because of lack of understanding about which genes affect a given quality. But basic research to study these proteins, using ELISA techniques and developing antibodies, should, if successful, make this technology available to breeding programs.

Biochemical Selection and Doubled Haploid Breeding.—These two new technologies involve tissue culture and the ability to form unorganized tissue (called callus) from organized plant tissue such as immature embryos and anthers on a culture medium and then to reform organized tissue that can be induced to regenerate into plants.

With biochemical selection, the unorganized tissues are challenged (exposed) to a chemical that inhibits normal growth. Cells that have undergone mutations or other genetic changes that make them resistant to the effects of the chemical will grow normally and can be identified. The power of this technique is that approximately 2.25 million cells can be grown in 30 milliliters (about 1 fluid ounce) of medium. Each of these cells potentially can regenerate into a plant. An acre of wheat by comparison, has from 1 million to 2 million plants, depending on seeding rate. For selection purposes, an ounce of cells capable of regenerating into plants is the numerical equivalent of 1 or 2 acres of wheat in a wheat nursery. It cannot be considered the functional equivalent, however.

While selecting directly in tissue culture to improve quality traits that are expressed in the seed may be difficult, selection may be possible for overproduction of essential amino acids that limit nutritional quality (30). Little variation for nutritional quality exists in wheat germplasm, and unconventional selection techniques may become an important objective for improving nutritional quality (e.g., lysine content) (33).

Wheat culture techniques to produce large quantities of regenerable cells routinely have not been refined. Few plant traits, including quality traits, can be selected at the cellular level. New biochemical strategies to improve nutritional quality probably will not be developed until tissue culture systems are developed fully, probably within the next 5 years. Again, as with genetic transformation technology, 7 years of testing and seed increase still will be necessary before the improved line would enter seed trade channels.

Doubled haploid breeding could shorten the time needed to develop inbred lines of wheat that normally are derived by generational advance following crossing. Most commercial wheat varieties are relatively homogeneous inbred lines, as are the two parents of hybrid wheats. The value of this technique is that when the chromosome number is doubled, each of its genes is copied identically.

The major limitation with doubled haploid breeding in wheat is that an efficient system for producing doubled haploids has not been developed. Using a relatively inefficient anther culture system, however, French researchers who developed the wheat variety Florin, released in 1987, believe they saved 4 years by reducing time needed for inbreeding.

SOYBEANS

Several thousand soybean strains were introduced from Asia in the early years of this century (28). Because soybean is photoperiod-sensitive, one of the initial tasks was to identify the potential adaptation areas for these accessions. A maturity group classification system was developed. Those materials adapted to northernmost latitudes were placed in Group 00 and those adapted to southernmost latitudes were placed in Group X. The soybean's potential value as an oilseed was recognized and plant breeding was begun for high oil and for adaptation to North Central States. The cultivars Dunfield and Illini, released in the 1920s, resulted from this breeding effort and their oil content became the standard for succeeding cultivars (9). Soybean was also used as a forage during this time, and prior to 1941 more soybeans were grown for forage in the United States than for grain (28). As soybean gained wider usage as a grain, breeding emphasis on seed yield increased. Early improvements in resistance to plant lodging, seed shattering, and foliar diseases increased soybean adaptability and helped make this a suitable grain crop for a wide geographical area (9).[2]

Objectives of Genetic Selection

Two major objectives of soybean improvement programs are to raise seed yield and to increase seed quality. As with wheat breeding programs, a third objective is the protection of current levels of yield and quality by increasing resistance to diseases, pests, and environmental stress. Because high yield has always been the primary attribute that farmers wanted in a new cultivar, it is the trait that has received the most attention. Comparisons of old and new cultivars have shown that significant improvement in soybean yield potential has occurred. In a test of Group I, II, III, and IV cultivars released between 1933 and 1971, yield increased by 50 percent. In a similar test of Group II and III cultivars released between 1923 and 1974, Wilcox et al. (62) found a total increase ot approximately 30 percent. Boerma (7) found that yields of cultivars in Maturity Groups VI, VII, and VIII had increased about 42 percent since 1914.

Resistance to insects has been an objective of some soybean breeding projects. Most research has been conducted in Southeastern States, where insects pose a greater threat to production. Although several insect species are pests, the genetic resistance that has been identified seems to have some effectiveness against many of them (37). Improved insect-resistant breeding lines have been released as germplasm, and one insect-resistant cultivar (Crockett) has been released in Texas.

Many studies aim at characterizing the genetic variation for protein and oil content in soybean and the genetic correlations between oil, protein, and seed yield (11). Yet for most soybean breeding projects, altering protein and oil concentration has been a low or nonexistent priority. Rather, the primary breeding goal has usually been high yield with maintenance of protein and oil at acceptable minimum levels, e.g., 41 percent protein and 20 percent oil. The well-documented negative relationship between protein and oil has meant that selection for either trait alone has resulted in a decline in the one not selected (10,13). Likewise, yield and protein are often negatively correlated and it has been difficult to increase both simultaneously (10). Soybean producers, the primary clientele of breeders, do not receive payment for the beans they produce according to chemical constituency. As a result, they have shown no interest in cultivars with high oil or high protein and this lack of interest has influenced plant breeding objectives.

Three cultivars have been released that are 8 to 12 percent higher in protein concentration. Protana and Provar were developed in Indiana and Iowa, respectively, and released in 1969 (57). Because the yielding ability of these cultivars was below that of other varieties being grown at the time, neither gained much acceptance by farmers. A third cultivar, Tracy, was developed in Mississippi, and because it had good yielding ability and resistance to *Phytophthora* rot and some foliar diseases, it achieved wide usage in Southeastern States. The cultivar Ransom, developed in North Carolina, has a higher than average oil concentration (23 percent). But it achieved wide usage because of its high yielding ability and not because of its high oil content.

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[2] This section is based on Joe W. Burton, "Soybean Breeding and Seed Quality," prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

While most soybean breeding has been directed toward increasing or protecting productivity, a considerable amount of research has also been aimed at developing germplasm with novel seed traits that would fit particular end uses and markets. These novel types, as usually visualized, would be sold outside the grain trade (probably on a contract basis) and thus have an opportunity to bring a premium price. The development of the cultivar Vance offers a good example of soybean breeding for a special end use. Vance was derived from a cross between the cultivar Essex and a wild soybean (*Glycine soja*) line. It has tiny seeds (8.8/100 seeds), which makes it very suitable for use in natto, a Japanese food product. Currently this cultivar is being grown in North Carolina and Virginia and is being sold directly to a Japanese importer for more than the soybean grain market price.

Tofu is another soybean food product that could be made from a specialty variety. While tofu can be made from any soybean, high protein seeds with yellow seedcoats and hila are preferred (22). The variety Vinton, which has 44.9 percent protein, was developed for this purpose (5).

Genetic Influences on Soybean Quality

Seed coat and cotyledon color are controlled by a relatively small number of genes. Likewise, small numbers of genes are usually involved in disease resistance. In cases like these where traits are simply inherited, genetic alteration is not difficult, provided the presence or absence of gene expression can be determined. Thus, the seed quality traits related to seed color and disease can be easily manipulated using standard plant breeding methods if genes for disease resistance have been identified in the soybean germplasm collection.

Protein and oil concentration (percentages) in soybean seeds and seed size are quantitative traits known to be under the influence of many genes. These can also be changed by classical plant breeding methods, but the task is usually more difficult. The challenge to plant breeders is mainly that of incorporating the large number of genes affecting the trait into an agronomically acceptable cultivar. This is complicated by the fact that genetic alteration of one trait frequently leads to undesirable changes in other plant characteristics.

When quantitative inheritance (i.e., controlled by many genes) is involved, knowing the heritability of a trait is the key to determining an appropriate plant breeding strategy for changing the trait. The expression of the quantitative trait depends on which genes are present in a given plant. Also, the trait is usually influenced by environmental conditions, which also contribute to the variation in expression. Heritability is a measure that estimates the proportion of the total variation in expression that is due to strictly genetic influences. Thus, as with wheat, a trait with high heritability is subject to less environmental influence, which means that the genetic worth of a particular plant is more easily determined. This usually means that progress in changing the trait through breeding is more rapid.

Johnson and Bernard (32), Brim (8), and Burton (13) have presented heritability estimates for quantitative traits that are usually measured in soybean breeding populations. The estimates were taken from several independent studies of different populations of soybean lines. Heritability estimates for seed protein percentage ranged from 51 to 92 percent. Seed oil estimates of heritability were similar, ranging between 51 and 93 percent. By comparison, seed yield estimates are lower, between 0 and 73 percent. This suggests that seed composition is less affected than seed yield by environmental factors. Thus, the genetic worth of a soybean line as it pertains to protein and oil composition is easier to determine than its genetic worth relative to seed yield.

Yield-Quality-Resistance Interactions

Breeding a cultivar for disease or pest resistance requires that resistance genes be incorporated into a high-yielding, agronomically acceptable genotype. If the resistance genes are located in a high-yielding adapted cultivar, then the transfer of resistance can usually be accomplished without yield loss. Such would be the case with resistance to soybean mosaic virus (SMV). High-yielding SMV-resistant cultivars are currently available. On the other hand, when resistance genes must be acquired from nonadapted plant introductions, transfer of resistance without some yield loss is difficult.

A major problem in selection for altered seed protein or oil composition in most soybean populations has been, as mentioned, the negative genetic correlations between protein percentage and the two other economically important traits, yield and oil percentage. Thus, selection for increased protein usually results in decreases in percentage oil and commonly in decreased yield (10,61). Similarly, selection for increased seed oil percentage results in decreased protein. Percentage protein and percentage oil were found to be negatively correlated in 12 soybean populations investigated in 5 separate studies (table 6-5). Most of these correlations had absolute values greater than 0.50. Negative correlations between percentage protein and yield, though frequent, were usually not great, with only 2 having absolute values greater than 0.50.

When considering the problems of genetically increasing the quantity of protein produced by a soybean crop, there must be a recognition of the producer's desire for high yield and the soybean processor's desire for high protein percentage and acceptable oil levels. Thus, breeding methods have been varied depending on the breeding goals. The negative relationship between protein and oil has led some investigators to attempt to increase protein indirectly by selection for low oil. This has some economic advantages in that percentage oil can be measured rapidly and nondestructively in soybean seeds by magnetic resonance imaging spectroscopy.

Increased protein yield can also be accomplished by selection for increased yield, provided percentage protein does not decline significantly. In this respect, recurrent restricted index selection could be used to hold protein constant while increasing yield. In two cycles of selection, using such an index, yield increased from 32.0 to 32.5 bushels/acre while protein and oil remained constant at 45.8 percent and 17.8 percent, respectively (31). It might be possible to select for protein yield directly, although there is the risk that percentage protein would decline.

Genotypic Variability

There is a wide range, approximately 15 percentage points, in seed protein percentage among lines of the U.S. soybean germplasm collection. About 10 percent of these have a protein percentage higher than 44.5 percent. Seed oil percentage for lines in the U.S. germplasm collection acquired before 1970 range between 13.2 and 23.5 percent. Because most currently grown cultivars have between 20 and 23 percent oil, there seems to be more opportunity for increasing protein than oil percentage with the germplasm resources currently available.

With the breeding methods mentioned in the previous section, genetic lines have been developed with higher protein content and similar yielding ability compared to standard cultivars. Three examples of such lines have protein percentages between 44.2 and 45.5 and were recently evaluated in the U.S. Department of Agriculture (USDA) Uniform Soybean Tests (table 6-6). When protein content was higher than the check cultivars, oil content was lower in these three lines.

Genotype v. Environment

As discussed in the section on wheat, variation in the expression of a quantitative trait in any plant population is due to genetic and environmental influences and an interaction be-

Table 6-5.—Genotypic Correlations in Soybeans

		Johnson et al. (1955)		Thorne and Fehr (1970)		Shorter et al. (1976)		Simpson and Wilcox (1983)				Openshaw and Hadley (1984)	
Population		1	2	3	4	5	6	7[a]	8[a]	9[a]	10[a]	11	12
Percent oil	genotypic	−0.48	−0.70	NA[b]	NA	−0.96	−0.35	−0.15	−0.96	−0.72	−0.36	−0.83	−0.68
Percent oil	phenotypic ...	−0.48	−0.69	−0.66[c]	−0.58[c]	−0.79[c]	−0.24	NA	NA	NA	NA	−0.80[c]	−0.65[c]
Percent yield	genotypic	−0.64	−0.12	NA	NA	NA	NA	+0.54	−0.74	−0.40	−0.20	NA	NA
Percent yield	phenotypic ...	−0.33	−0.08	−0.21	−0.27	NA	NA	NA	NA	NA	NA	NA	NA

[a] Random F_6 lines from crosses between unadapted high protein lines and adapted average protein lines (UH X AA)

[b] NA = not applicable

[c] Significant at <0.5.

SOURCE: Office of Technology Assessment, 1989.

Table 6-6.—Mean Performance of Check Cultivars and Breeding Lines With Higher Percent Seed Protein

Line	Yield (bu/acre)	Protein (percent)	Oil (percent)
D82-4098[a]	45.8	44.2	18.1
Centennial	43.8	42.9	19.0
N84-1256[b]	37.0	45.5	18.7
Check cultivar[c]	37.5	41.5	21.0
LN82-4049[d]	45.4	44.8	20.2
Sparks	44.0	41.2	21.5

[a] Tested in the Regional Preliminary VI, The Uniform Soybean Tests—Southern Region, 1984.

[b] Tested in five North Carolina environments.

[c] Braxton, Ransom, or Gasoy 17.

[d] Tested in the Regional Preliminary IV A, The Uniform Soybean Tests—Northern States, 1985.

SOURCE: Office of Technology Assessment, 1989.

tween the two. In defining issues related to the interaction of genotype and environment in plant breeding, it is helpful to consider environmental variation in a continuum from predictable to unpredictable. Predictable variation is due to those conditions that can be controlled in some way (e.g., irrigation) or those that have permanent characteristics (e.g., photoperiod and soil type). Weather-related conditions generally contribute most to unpredictable variation.

Most problems in seed quality that arise because of weather have no real genetic solutions. Sometimes, genetics can lessen the impact of a weather-related problem. For instance, the hard-seed coat genotype develops less seed disease when harvest is delayed after maturity. Other genetic sources of resistance to fungal seed pathogens lessen the problem but do not eliminate it. Many seed disease problems are related to cultural practices and harvest. Usually changes in farming, harvesting, and storing practices are much more likely than varietal disease resistance to be effective in controlling seed disease.

Most soybean breeding programs have regional testing efforts to evaluate genotypes across a wide array of environments. A genotype is selected from these tests on the basis of ability to perform well in most environments. Statistical analyses have been developed to determine the relative environmental stability of cultivars. Evaluation and selection of stable cultivars is the most common way that environmental influence is moderated by genetics. The other way is to attempt to tailor a variety for a particular environment. This can be quite successful if the environment can be defined. Breeding for disease resistance fits this category.

Role of Public and Private Soybean Breeders

Private industry investment in soybean breeding has been a relatively recent development. Prior to the passage of the Plant Variety Protection Act in 1970, only six companies (with one plant breeder each) were engaged in soybean breeding because soybean is a self-pollinated crop and, without the act, research investment could not be recovered. Since then, an additional 25 companies and 61 breeders have been added to the private soybean breeding industry (63). Under the act, certificates of plant variety protection can be issued that assure the "developers of novel varieties of sexually reproduced plants . . . exclusive rights to sell, reproduce, import or export such varieties." It was this guarantee of exclusive rights that enticed private seed companies to invest in soybean research. Thus, the role of the private plant breeder is to develop novel soybean varieties that can be sold at a profit.

Public soybean breeders have always been involved in varietal development. Yet they have had and continue to have a large role in basic soybean breeding. The roles or responsibilities of public breeders in general have been identified as to teach and train students as future plant breeders, conduct "basic" research, and develop cultivars of minor and regionally adapted crops (52). This latter would obviously not apply to soybean breeders. General agreement exists among those concerned with this issue that training students is an important and appropriate responsibility of public breeders, and most agree that public breeders should conduct basic research.

The changing role of publicly supported plant breeding research was discussed at the 1982 Plant Breeding Research Forum sponsored by Pioneer Hi-Bred International, Inc., which was attended by both public and private plant breeders and administrators. The joint effort between public and private breeders was reported in the conference proceedings as being mutually beneficial. Furthermore, the competition in crops such as soybeans was considered to be healthy because there is no assurance that developing varieties of self-pollinated species will be profitable enough for private companies to justify continued research investment, because it is not possible to draw a line separating basic from applied plant breeding, and because no clear division exists between germplasm enhancement and cultivar development (43).

General agreement exists that increased support for basic research is needed, particularly that involving the collection, assessment, and development of germplasm resources (43,52). This is needed simply to maintain current levels of crop productivity. The average lifetime of a soybean cultivar in the United States is 5 to 9 years, in part because of the dynamic nature of the agroecosystem. The sudden appearance of a disease, changes in climate, water, or soil conditions, or changing cultural practices can necessitate the replacement of a cultivar with one more adapted to the new environment. This situation is not likely to change. The new genetic engineering technologies, such as protoplast fusion, if successful, will be a useful tool in cultivar development but will not eliminate the need for traditional plant breeding research activities.

Rational for Differentiation

Private plant breeding programs have basically one goal—the development of an improved cultivar that can be marketed and profitably sold to farmers. This permits a concentrated investment of resources for cultivar development that is usually much greater than a similar investment by a public plant breeding program. For example, in 1983 Asgrow Seed Co. made 1,200 crosses combining genetically different material and screened 120,000 lines with a professional staff of five Ph.D. plant breeders (4). By comparison, the public soybean breeding program at North Carolina State University in a typical year makes approximately 6 crosses aimed at cultivar development and screens approximately 1,200 lines for agronomic performance.

Research funds and scientists' time at most public institutions that conduct soybean breeding are spent on a variety of activities not directly related to cultivar development, such as teaching, evaluating germplasm, devising and testing breeding methodologies, and doing inheritance studies. Without a profit motive, publicly funded soybean breeders are usually under less pressure than private soybean breeders to develop and release cultivars. Publicly funded soybean breeders also are freer to conduct long-term research projects that have a low probability of yielding any immediate economic return. The "high risk" nature of basic research means it probably will only be conducted by public institutions (43).

Funding

Soybean breeding by a private company is funded by profits from the sale of seeds of the varieties the company produces. If soybean varieties are not profitable, then the funds come from some other division of the company that is profitable. Funding decisions are based on company managers' assessment of the market potential for soybean varieties with particular characteristics—e.g., maturity group, resistance to a disease, and so on.

Soybean research has four sources of public funding. These sources and their relative contribution in 1984 were:

- State appropriations (37 percent);
- USDA-Agricultural Research Service (29 percent);
- Hatch Act formula (10 percent); and
- funds to land grant universities and contracts, grants, and cooperative agreements from Federal, State, and farmer check-off sources (24 percent) (3).

Farmer check-off in the 1980s has amounted to between 7.4 and 8.1 percent of the total soybean research funding. Grower funding varies a great deal among soybean-producing States.

Grower funding in 1984 amounted to 25.7 percent of the total soybean research budget in Nebraska, whereas in Ohio there was none.

Even though studies measuring return to investment in agricultural research show rates of at least 15 percent, State and Federal support (in real dollars) for agricultural research has remained nearly constant since 1965 (43). In recent years, as plant breeding positions in public institutions have become vacant, they have been converted to genetic engineering positions so that research in biotechnology can be emphasized. This has meant an overall decrease in funding of traditional plant breeding research. This reduction in public support for plant breeding is generally viewed with great concern.

Alternate means of financing public plant breeding research are being explored. One suggestion is that private industry become more involved. For instance, a private company could support graduate student training and research. It is also suggested that private industry could support research that benefits the industry itself. Some State universities are considering patents on products of their plant breeding research as a means of generating revenue. Increased funding from commodity organizations is another possibility.

All these suggestions have been criticized because funding of this nature is usually unpredictable and tied to particular short-range goals. It does not provide for the long-term, higher risk research that requires a continual resource commitment. A recent suggestion has been the release by State Agricultural Experiment Stations of soybean varieties eligible for royalties, by the brand name Variety Not Stated. This idea has not been viewed favorably by either public or private soybean breeders. It is believed that such a system would tend to shift more resources toward short-term basic research, impede the free flow of germplasm among experiment stations, and limit a farmer's ability to know whether or not two varieties are identical.

Variety Release

Prior to 1946, 194 soybean cultivars were released in the United States and Canada (table 6-7). Nearly all were plant introductions from Asia or plant selections from those introductions. Active soybean breeding increased after 1945. Between 1946 and 1970, 110 cultivars were released from public plant breeding projects. As noted, private soybean breeding increased with the passage of the Plant Variety Protection Act in 1970. Between 1973 and 1987, a total of 363 soybean cultivars were released under plant variety protection (table 6-8). Most of these were developed by private soybean breeding projects. Sixty-four public cultivars in maturity groups 00 to IV were released between 1971 and 1981 (51), and in maturity groups V to VIII, 93 public cultivars were released (29).

As the number of public varieties has increased, the number of acres planted with private cultivars also has increased. Currently 57 private cultivars are available to farmers in North Carolina v. 23 public cultivars. The North Carolina acreage planted to public cultivars has decreased from 81.4 to 62.7 percent in the past 4 years (19). The trend toward increased use of private cultivars will probably continue due to the release of improved private cultivars and the ability of private companies to market effectively.

Procedures for Release

Most soybean cultivars are the inbred progeny from matings between two or three inbred lines or cultivars. They are usually "pure" lines, which means they have a high level of genetic homozygosity from having been inbred through at least three generations of self-pollination. A soybean breeder selects the "best" inbred lines from among several populations. These lines are tested in local and regional tests before a decision is made to recommend the line for release as a cultivar. This decision is made based on its yielding ability relative to currently grown

Table 6-7.—Soybean Cultivars Released by Public Institutions in the United States and Canada Prior to 1976

Maturity groups	Prior to 1946	1946-70	1971-76	Total
00-I	35	29	8	72
II-IV	98	54	12	164
V-VII	43	22	6	71
VIII-X	18	5	4	27
Total	194	110	30	334

SOURCE: T. Hymowitz, C.A. Newell, and S.G. Carmer, "Pedigrees of Soybean Cultivars Released in the United States and Canada," International Agricultural Publications, INTSOY Series No. 13, University of Illinois, Urbana-Champaign, IL, 1977.

cultivars in the same maturity grouping. Decision to release is also based on other traits that contribute to agronomic quality and yield stability over a range of environments. In approximate order of importance, these traits include resistance to plant lodging, disease and pest resistance, stress tolerance, rate of emergence, and protein and oil content.

Every State Agricultural Experiment Station or private seed company has a committee that reviews and approves prospective cultivar releases. A soybean breeder who has selected a line that is suitable for release as a cultivar must prepare a report or "defense" of the line. This includes a summary of pertinent test data and a statement of the rationale for release. The latter explains the unique characteristics of the line that would make it an important addition to available cultivars. Productivity and usefulness to growers are the primary criteria in releasing new varieties. For private plant breeding companies, stability is also a critical consideration. Because a company's name and reputation are associated with the cultivars they release, the firm cannot afford to release a cultivar that performs poorly.

Every State has its own cultivar release policies, although these have all been developed within the guidelines of USDA policy (57) and Federal law (Federal Seed Act of 1939 and Plant Variety Protection Act of 1970). As an example, the North Carolina Agricultural Research Service makes the following statement in its Plant Patent and Plant Variety Protection Policy and Procedure Statement:

Table 6-8—Soybean Cultivars Released by Private Companies Under Plant Variety Protection Certificates, April 1973-November 1987

Company	Number of PVP cultivars not under Title V	Number of Title V PVP cultivars
Agratech Seeds		1
Agripro, Inc.	7	
Americana Seeds, Inc	1	
Asgrow Seed Co.	48	
B.B. Collier-Barney A. Smith		1
Bryco Plant Research Division	1	1
BSF/Ag Research	1	
Callahan	6	1
Coker's Pedigreed Seed Co.	22	16
Dairyland Seed Co., Inc.	3	8
Delta & Pine Land Co.	7	1
Ferry-Morse Seed Co.	1	
FFR Cooperative	8	1
Funks Seeds		1
Goldkist		1
Growmark, Inc.	1	
Helena Chemical Co.	5	
Identity Seed & Grain Co.	1	
Illinois Foundation Seed		1
Jacob Hartz	9	3
Jacques Seed Co.	8	
J.M. Schuetz Seed Co.	8	
King Grain U.S.A., Inc.	4	
Land O'Lakes, Inc.	11	
Louis Bellatti		2
Lynnville Seed Co.	4	1
Midwest Oilseeds, Inc.	4	
Milburn Farms		1
Nickerson American Plant Breeders	6	
Nixon Seed Co. & L.		1
North American Plant Breeders	26	
Northrup King Co.	24	15
Pioneer Hi-Bred International, Inc.	40	1
Prarie Seed Co., Inc.	1	
Scientific Seed Co., Inc.	1	
Soybean Research Foundation, Inc.	13	20
Stanford Seed Co.		1
Syler	1	
Terral-Norris Seed Co., Inc.		7
Teweles Seed Co.	4	
Voris Seeds, Inc.	1	
V.R. Seeds, Inc.	8	
Totals	278	85

SOURCE: Office of Technology Assessment, 1989.

> New plant cultivars and breeding lines may be released for public use if judged to be either unique or superior to currently available germplasm, or equal to presently available cultivars if the genetic base of a crop is broadened so as to reduce disease and other pest hazards (40).

The statement encourages release of new cultivars that enhance yield, but makes no mention of quality.

Length of Time for Development and Release

In a survey of 64 Plant Variety Protection applications for soybean cultivars, the average time required from cross to application was 9.2 years (4). This development and release time is similar for private and public cultivars. The use of a winter nursery in the inbreeding stages can shorten the time between making a cross and development of a pureline that has variety potential. This has already become common of all soybean breeders, however, so the 9.2-year estimate would include the time savings involved in winter nursery use.

New biotechnologies are unlikely to reduce significantly the time for development and release of a cultivar. They will, however, provide the opportunity for putting a new trait into a plant in a matter of months where now it can take 5 to 7 years to breed into a variety a specific trait through conventional breeding and backcrossing. Field testing and seed manipulation steps are still necessary and will consume most of the development and release time.

Soybean Breeding Technology

Present Technology

Soybean cultivars are typically developed by hybridization of two or more lines followed by self-fertilization to the F_4 or later generation. Homozygous lines (purelines) are isolated and tested to determine those with superior performance and cultivar potential. With this method, the major issue has been how material in the F_2, F_3, and F_4 segregating generations should be handled. The method used depends on the plant breeding objectives and personal preferences of individual soybean breeders. Pedigree selection or modified pedigree selection are the most common methods for systematic inbreeding (22). Backcross breeding is commonly used for transferring a few gene loci from a low-performing line to a high-performing cultivar. Modification of those standard practices include population improvement through early generation testing and recurrent selection, bulk breeding, and mass selection.

The other important issue that has received considerable attention is the most appropriate and efficient way to evaluate lines with respect to a particular trait. Various field plot and laboratory testing techniques have been developed and used (22). The appropriateness of a particular technique depends on the trait being evaluated and the ease with which it is measured. Much of the success or failure of a particular breeding project can be attributed to the quality of the germplasm and the genotypic evaluation program.

These classical methods are adequate for the transfer and recombination of genes within the species and have been successfully used to improve soybean cultivars. Higher yielding cultivars with disease and pest resistance have been developed and released over the past 40 years. Progress, while continuous throughout this period, has been slow. The rate of increase in seed yield has been estimated at between 0.6 and 1.0 percent per year (62). For at least the next 10 years, the classical methods, because they are in place and successful, will likely continue to be those most used to produce improved cultivars.

It is currently not possible to economically produce the seeds for F_1 soybean hybrids. Patents for two F_1 hybrid seed production methods have been issued. However, it remains to be demonstrated that either can be used to produce hybrid seed economically. Strong evidence for significant hybrid vigor in the soybean species is sparse (13). As a result, little research is being conducted on F_1 hybrid seed production for soybeans.

Future Technology

Future technology in the genetic alteration of soybean will undoubtedly include recombinant DNA methods (genetic engineering). Some progress is being made in the regeneration of whole, fertile plants from soybean tissue and cells in culture. But it is impossible to predict how long it will be before regeneration becomes routine. Various methods for transferring genes into plants are being developed, and plant transformations have been successful. For instance, a gene that imparts tolerance to glyphosate herbicide has been introduced into *Petunia* (48).

If methods for foreign gene transfer and regeneration are developed for soybean, the same problems as in wheat will still apply—isolating genes, determining which ones can be beneficially introduced into a plant, and regulating the gene expression once it is introduced. In soybean, the traits most likely to be altered through genetic engineering are seed protein and oil quality, plant stress tolerance, pest and disease resistance, and herbicide tolerance (26). It is expected that desirable changes in these traits can be obtained by manipulating a few genes. As of now, not many soybean genes have been cloned, sequenced, and had the gene product isolated. More basic genetic information is needed about plant traits in order to make significant changes in soybean through genetic engineering (26).

Only the seed quality traits that are related to disease reaction, such as the mottling caused by soybean mosaic virus, are likely to be affected by new genetic engineering technologies in the near future. Percent seed protein and oil and seed size, like seed yield, are polygenic. Many unidentified genes are involved in the determination of these traits. This makes them difficult to evaluate at the cellular level and to work with at a molecular level (27).

The new molecular genetic technologies hold great promise, and much important biological information will be learned from molecular genetic research. This will eventually translate into practical ways to alter plants genetically in a desirable way. In the short term, however, most improvement in soybean seed quality will come through classical plant breeding.

CORN

Corn is the only important cereal crop indigenous to the Americas, and more than twice as much corn is produced in the United States as any other crop. Most modern races of corn are derived from prototypes developed in Mexico and Central and South America. An exception to this is the sole product of North America—the yellow dent corn that dominates the U.S. Corn Belt, Canada, and much of Europe today. The late maturing Virginia Groundseed and the early maturity Northeastern Flints were crossed in the early 1800s, and the superiority of the hybrid was recognized. The cross was repeated many times and out of these mixtures eventually emerged the Corn Belt dents, the most productive race of corn found anywhere in the world. The highly selected cultivars of Corn Belt dents formed the basis of hybrid corn and were the source of the first inbred lines used to produce hybrids.[3]

Objectives of Genetic Selection

Corn breeding is accomplished by selection for desired plant traits during both inbred development and hybrid evaluation. Breeders have always selected for traits that give higher yield and easier harvest in accordance with current cultural practices, and harvest method has been the most important cultural practice influencing selection traits for corn. Quality factors such as protein or starch content have not been a high priority.

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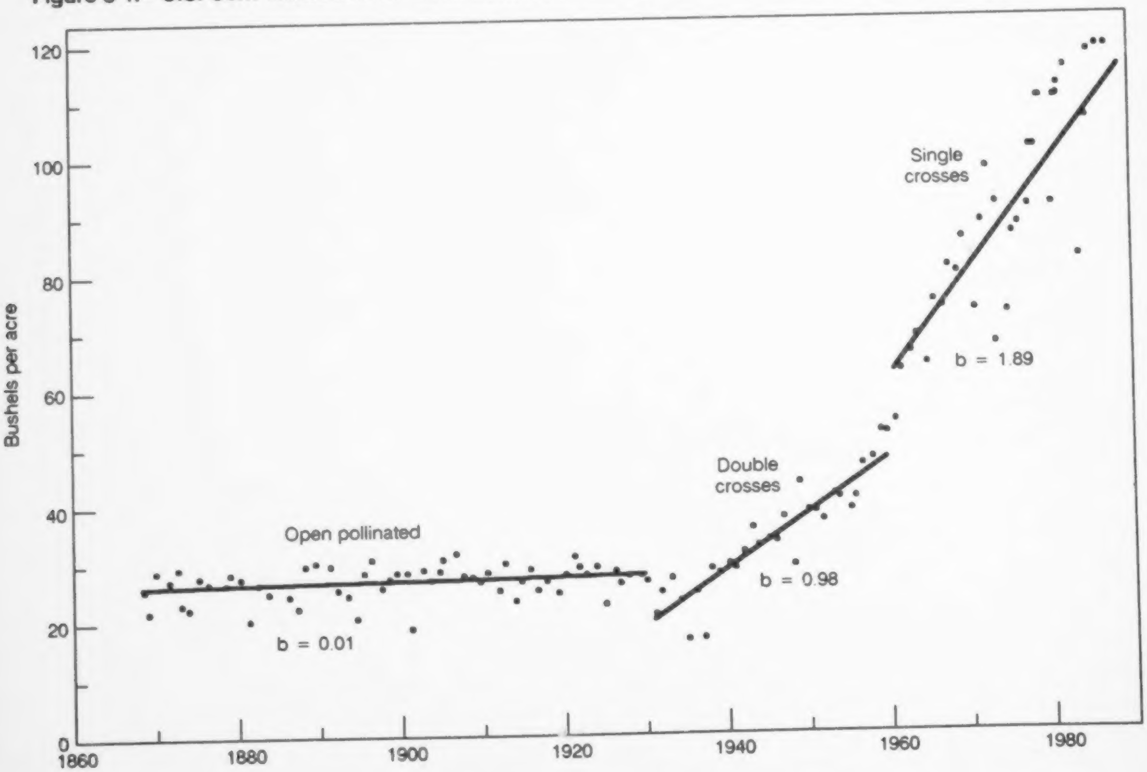
[3] This section is based on A. Forrest Troyer, "Grain Quality and Corn Breeding," prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

Since the introduction of hybrid corn, the U.S. average corn yield has increased steadily, from 16 bushels per acre in 1936 to 110 bushels per acre average for 1981 through 1987. Since single-cross hybrids (circa, 1960), the average yield increase per year is 1.89 bushels (figure 6-1). Most of this yield increase is genetic improvement. Three investigations (14,20,44) compared yields of hybrids from various eras; the gain in hybrid performance due to breeding averaged 64 percent of the total gain in annual corn yields (table 6-9). The other 36 percent has been attributed to improved cultural practices such as fertility, weed control, plant density, planting date, row width, etc. Corn breeders have successfully matched breeding objectives with improved cultural practices steadily and rapidly to increase national average yields of corn and will continue to do so in the future (55).

The other major objective of corn breeding has been to accommodate harvesting methods. Hybrid corn made mechanical pickers possible because of better standability. The corn-picker-harvest period (1940-60) saw many corn production improvements; increased fertilizer use, higher plant densities, more continuous corn, improved herbicides and insecticides, cheaper nitrogen, and earlier planting were some of the more important. Cold tests and other indicators of seed vigor were devised by breeders to develop corns adapted to earlier planting. Plant and ear height were unaffected by use of corn pickers. Most farms were still diversified, and livestock consumed much of the corn on the farm where it was grown. Breeders selected corns that would not shell too easily on snapping rolls and on husking beds of corn pickers. Continuous corn led to root-

Figure 6-1.—U.S. Corn Yields and Kinds of Corn Over Years (b values show average yield increase per year)



SOURCE: A. Forrest Troyer, "Corn Breeding and Grain Quality," presented to North American Export Grain Association, May 1986

Table 6-9.—Summary of Studies on Breeding Gain in Corn

Study	Hybrids (number)	Period (years)	Gain (percent)
Duvick, 1977	19	32	57
Duvick, 1977	50	40	60
Russell, 1974	25	48	63
Castleberry et al., 1984	27	60	75
Average	30	45	64

SOURCE: Office of Technology Assessment, 1989.

worm buildup and strains of insecticide-resistant insects, so stronger rooted hybrids were needed. Farmers preferred hybrids that picked cleanly and easily, so breeders selected for smaller shank-to-ear attachment. Use of higher plant densities required selection by breeders of corn genotypes that tolerate stress due to plant crowding. About the same maturity corns were still being grown in a given area (generally full season), and test weight still was not a problem because corn sold off the farm was naturally dried ear corn.

The field-shelling-harvest period (1960 to present) has brought larger farms, higher plant densities and fertilizer rates, even more continuous corn, and more corn marketed off the farm (55). Artificial dryers became commonplace throughout the Corn Belt. For a time, large farms and small equipment increased the need for better standing corns, and newer combines and other equipment steadily increased operational capacity. Corn became shorter and lower eared in this period as farmers shifted to earlier corns in order to start combining sooner. Before the invention of quick-attach heads for combines, stalk quality became extremely important to large operators in cash-grain operations because corn harvest often waited until soybean harvest was finished. Ear retention was also very important to these operators. Harder starch, or flintier types, allowed earlier start of harvest by reducing the number of broken kernels with high moisture shelling. Artificial drying of corn (which lowers test weight), coupled with more direct selling from the field with test weight discounts, further increased the need for harder textured, flintier corns. Hybrids with stronger cobs and easier shelling became an advantage for combine harvest, while those that dried faster in the field and in the dryer became more desirable as fuel costs rose (54). Genetic selection for tolerance to higher plant densities reduced barrenness and increased frequency of two-eared plants. Adoption of minimum tillage to cut costs increased the incidence of diseases and insects (gray leaf spot, corn borer, etc.), leading to more breeding emphasis on these problems.

Genetic Influences on Kernel Quality

Corn kernels can be altered by genetic means to give modifications in starch, protein, oil, and other aspects such as kernel hardness.

Starch Modification

Most genes affecting endosperm composition are recessive. Starch from normal dent or flint corn is composed of 73 percent amylopectin (starch fraction with branched molecules) and 27 percent amylose (the fraction from linear molecules). Corn breeders have been successful in developing waxy corn that has starch with 100 percent amylopectin. However, yields of the waxy hybrids were less than those of their normal dent counterparts. But newer waxy hybrids are comparable to the better dent varieties. It has also been possible to increase the amylose content of starch up to 50 percent. Waxy and high-amylose hybrids are grown under contract for corn wet-milling.

Oil

The oil content of most hybrids ranges from 3.5 to 6.0 percent, with an average of about 4.5 percent. Experiments indicate that oil content can range from a low of 0.1 percent to as high as 19.6 percent (18). High oil hybrids with 6 percent oil content and above are lower in yield than hybrids with less than 6 percent oil. Increasing oil content genetically is not difficult, because variation occurs in existing germplasm and most of it is heritable (2). Oil quality is a function of the relative amounts of unsaturated and saturated fatty acids, the amount of which is under genetic control and can be altered through breeding.

Analyses of hybrid crosses have shown a negative correlation of −0.49 between yield and percent oil. Data from these experiments suggest that for significant increases in percent oil content, yield would have to be sacrificed.

Protein Quantity

The amount of protein in corn is a function of cultural practices and heredity. The current average protein content of U.S. hybrids ranges between 9 and 11 percent. Through selection, protein can be altered. Experiments covering 70 generations of selection for protein have produced corn with a low of 4.4 percent protein and a high of 26.6 percent (18). But there is a trade-off between higher protein and yield. Genetic correlations between yield and protein range from −0.41 to +0.34 and average −0.06 (17). Data from these experiments indicate that within an intermediate range of approximately 14 to 18 percent protein, yield and protein can be increased simultaneously. For higher ranges of protein, yields will decrease. Not much interest exists in developing hybrids with higher protein potential, however, because economically available soybean protein can produce an animal feed ration that is balanced with respect to the essential amino acids.

Kernel Integrity

Damage to kernels during harvesting, drying, elevating, and moving grain through commercial channels is of concern. Contributing to the problem is the change from harvesting on the ear to using field picker-shellers. Artificial drying was usually not needed for corn harvested on the ear, because it dried naturally in the corn crib. Combine harvesters allow harvesting corn earlier to reduce field losses; however, grain usually has a high moisture content and requires artificial drying. Most farmers dry grain rapidly at high temperatures because of the small drying capacity of equipment, but this excessively rapid removal of moisture causes cracks to occur in kernels. When grain is moved through market channels, kernels break easily, resulting in fine particles that lower the value of the product.

Methods of determining breakage susceptibility have been developed that indicate many kernel characteristics are related to the breakage problem. These include the ratio of vitreous to nonvitreous endosperm, kernel density and average weight, test weight, and kernel size and shape. Most of these characteristics are heritable, but corn breeders have not given high priority to selection for kernel breakage reduction. Research also indicates that differences exist among genotypes for kernel fracturing caused by fast, high-temperature drying. Selection for resistance to this kind of kernel fracturing should be possible.

Another solution to the problem is to allow corn to dry in the field to a moisture content that would require less artificial drying. Development of fast-drying hybrids is possible.

Genotype v. Environment

The environment greatly influences the quality of grain. Fall seasons with much rain can increase ear rotting. The need for fast drying in the field has caused selection of hybrids with less husk cover. These same hybrids may lack ear protection from heavy rainfalls. The best hybrid for fast drying in a normal autumn may be the worst hybrid for ear rot in a high-rainfall autumn. Early frosts may cause premature death that reduces kernel size and test weight. Dry seasons in general favor insects because insect parasites are inhibited by lack of moisture. Insects reduce grain quality by increasing broken kernels, foreign material, and kernel rot.

Genotype v. Management

Protein content can be increased with nitrogen fertilizer. If the base yield is 75 to 100 bushels per acre with 8.5 percent protein, and the final yield with extra nitrogen is 100 to 125 bushels, the first 100 pounds of nitrogen will probably raise the protein about 1 percent. The next 100 pounds will raise the protein another 0.5 percent (1). Higher protein contents have been found in corn after drought conditions because a fixed nitrogen amount is distributed through a smaller crop (25). This is because most nitrogen accumulation precedes endosperm filling. Only one-fourth of the protein in the kernel is in the endosperm. The endosperm increases in size with higher yields and is mostly starch—86 percent starch and 9 percent protein (60). Thus, a negative association occurs between yield and percent protein at high yield levels or at low nitrogen fertilization levels.

Plant density can affect quality when enough stress occurs to cause misshapen ears that may dry slowly or have many small kernels. Grain texture may also be affected by stress. Late planting dates reduce quality by causing flowering during hot weather and an immature crop at harvest with effects similar to early frost.

The chosen drying method is a big factor in corn quality. When corn was harvested on the ear and dried slowly in the crib, test weight and broken kernels were no problem. Field shelling (combining) has changed all that. In the northern and central Corn Belt, harvest at high moisture followed by rapid drying at high temperatures can cause puffing and case-hardening that reduces test weight and increases brittleness. In the southern Corn Belt, ear quality can deteriorate in the field during humid fall conditions.

Ear-corn storage has given way to shelled-corn storage. As mentioned before, these changes in harvest methods have greatly affected corn breeders' selection traits. Stored corn typically has problems with molds and insects that interact with moisture content and temperature of the corn.

Role of Public and Private Corn Breeders

Corn breeding at the Federal, State, and private level greatly increased subsequent to the double-cross-corn formula of hybrid production that made hybrids practical in spite of the weak inbreds and cultural practices of the period. In 1955, the Federal Government spent $300,000 ($80,000 for basic research), State Agricultural Experiment Stations (SAES) no more than $150,000, and private companies at least $2 million on corn breeding and yield testing (59). Estimates for 1987 are Federal Government (USDA) $4 million, State Experiment Stations through the Cooperative State Research Service (CSRS) $8 million, and private companies more than $70 million. For comparison, the 1987 Federal budget contained $35 million (USDA Agricultural Research Service) and $46 million for State Experiment Stations (CSRS) for projects related to biotechnology (6).

Until about 1960, for new inbreds most SAES had delayed-release programs that served to maintain State crop improvement programs by favoring companies that sold State-certified hybrids. Delayed release policies plus the Federal Seed Act of 1939 (58), which prohibits selling the same pedigree under different names, were to exclude new public inbreds from private label seed companies. However, the Federal Seed Act does not prevent this. Public inbreds have been used in crosses and sold under different names (39). This confuses the farmer and prevents the spreading of risk unless the pedigrees of the purchased hybrids are known.

At the beginning of hybrid corn, many small seed corn companies were enticed into the business by promises of new inbreds from the State Agricultural Experiment Stations. Inbred lines from public agencies became the parental lines for SAES commercial hybrids and for development of new inbreds. By the late 1950s, larger seed corn companies had extensive research programs to develop inbreds, and public breeders started doing additional basic research at the expense of inbred development. A total of 156 public lines were released from 1946 to 1955. An American Seed Trade Association survey of the same period showed 52 hybrid corn companies in 12 States were using these lines as 1 or more parents in producing about one-fourth of the hybrid seed used annually. About 500 individual companies produced and sold hybrid seed in Iowa in 1940; only about 100 companies were still in operation in 1957. Observers of these changes concluded that publicly supported corn research was more basic than 10 years earlier and that breeders involved felt even more time should go to basic research.

Variety Release Procedures

The United States places few restrictions on the release of new corn varieties developed by public or private breeders. Release of new varieties takes place at agricultural experiment stations within the land-grant system. Private breeding takes place at research stations operated by private firms around the country. Most States have laws that control labeling of new varieties but these usually deal with seed purity or certification procedures. For example, most State seed laws specify the information required on the tag on each bag of seed. Michigan appears to exert more influence on variety release than other States. According to breeders there, public varieties cannot be released unless they show an "acceptable level cf merit."

Public Varieties

As public breeders, agricultural experiment stations around the country follow general guidelines set forth by the seed policy committee or the general executive committee for research, entitled ESCOP (Experiment Station Committee on Policy). ESCOP is organized under the Experiment Station Section of the Division of Agriculture of the National Association of State Universities and Land Grant Colleges in Washington, DC. The seed policy subcommittees under ESCOP represent experiment stations on seed matters, including production and technology, in appropriate agencies and associations. General policies regarding variety release procedures and other breeding issues are established through these committees. A function of ESCOP and its seed policy committee is to maintain consistency in procedures and policies regarding release of public varieties. ESCOP holds no legal power over experiment stations or variety releases.

The variety release decision within each State's experiment station involves a committee within the College of Agriculture. At the University of Illinois, for example, this committee is called the PVRC (Plant Variety Review Committee), and it serves in an advisory capacity to the Dean of the Experiment Station who is appointed by the Chancellor of the University. Each State Agricultural Experiment Station that has an active breeding program has a PVRC similar in function to that at the University of Illinois. Although patenting of germplasm and plant protection of varieties are currently being discussed, the general philosophy of public institutions regarding variety release has been one of information exchange and minimum control.

Private Varieties

Evaluation of new varieties developed by private firms occurs without significant State or Federal intervention. The decision to release a new variety is an internal one arrived at by review committees that vary according to firm size.

Each plant breeding company in the United States has a procedure for determining the usefulness or worthiness of new varieties. These procedures are generally informal in the case of smaller companies, but more formal and structured in the case of larger firms. The decision to release a new variety often evolves during a series of meetings with company administrative personnel, breeders, sales staff, and so on. Large companies (nationals and multinationals) do their own screening and testing of new varieties, and the data are made available at each variety review stage. Recommendations on retesting, rejection, and release are made on the basis of performance data and advice from company personnel. A large firm might start out with several thousand crosses and end up with just a couple that actually meet all necessary criteria. In private firms, the criteria reflect field performance data as well as information on the potential for effective sales, marketing, and advertisement. All of these are related to the firm's profitability.

Michigan is an exception among the Midwest corn-and soybean-producing States in that State law requires public or private certified seed to be subjected to performance trials for at least 1 year before it can be sold as certified seed. This does not preclude selling uncertified seed, nor does it prevent companies from other States selling seed within Michigan that has not been subjected to these tests. It does prevent any dealer in Michigan from labeling seed as certified unless it has been subjected to the performance tests established under authority of the State.

Field Performance Criteria

In a 1981 survey, 454 commercial hybrids were offered for sale; 212 precommercial hybrids were in final testing stages; 7,400 experimental hybrids were in advanced trials; and 61,000 hybrids were in preliminary trials. About 2,800 proven inbreds were on hand and 23,000 inbreds were in preliminary tests (21).

Criteria for judging new varieties in the field are similar for both public and private breeders. Performance criteria for measuring corn varieties are more diverse than those for judging soybeans and wheat. For all grains and soybeans, yield is the number one criteria as breeders try to persuade farmers that their variety is superior to others in the market.

Private and public corn breeders interviewed for this assessment stated that after yield, the ranking of remaining performance criteria differs among firms. This is in part a response to different environmental factors, herbicide developments, or changes in production practices that prompt a change in research emphasis. Variation in the relative importance of field performance criteria may also relate to differences in the ability to measure various performance criteria and differences in terminology among firms, since many performance judgments appear to incorporate some subjective factors.

Several corn breeders indicated that for corn, disease and pest resistance is the second most important performance criterion, with the third being maturity, i.e., length of dry down time required in the field. One firm indicated that standability was the second most important factor, while another ranked standability seventh. Again the difference probably relates to the firm's ability to measure standability and to how directly the firm relates standability to dry down time or disease resistance. Other criteria, ranked loosely in order of importance, are herbicide tolerance, feed value, percent early stand, plant height, percent dropped ears, flowering date, percent barren plants, and test weight.

Corn Breeding Technology

Most U.S. Corn Belt germplasm used today involves only two races, southern dents and northern flints, but more than 100 fairly distinct races of corn exist. From this standpoint the available germplasm base is more than adequate. Considerable genetic variability exists among kinds of corn in terms of adaptation, size, and purpose. It is likely that all traits currently needed to improve corn quality already exist. The problem is to identify exactly what is needed so that seedlots in germplasm banks can be efficiently screened for necessary traits. Certainly a large range of test weight, kernel texture (ratio of hard to soft starch), and kernel size is presently available among materials actively being used by U.S. corn breeders. The hope that an existing, unidentified trait for kernel integrity can be found depends on an accurate and rapid test to identify it.

As noted, present corn breeding technology has worked well. U.S. average yields are increasing almost 2 bushels per acre per year largely due to the highly competitive seed corn industry striving to provide hybrids that give the highest net profit to the farmer. Corn breeders today emphasize high yields, easy harvest, and fast dry down with modern cultural practices. The current system relegates corn quality to fourth rank or lower. Making grain quality or any other desired trait more profitable to the farmer will stimulate more breeding effort for that trait under the present system.

Future corn breeding technology will include more of the present methods plus the biotechnology approaches discussed in the wheat and soybean sections. Successful breeders are fitting these newer technologies into present methods. Transformation of plants with genes from other species and with engineered genes may provide the needed trait with less effort and fewer side effects than screening various germplasm storage banks. Ultimately, it may be possible to build a needed DNA sequence and position it into elite lines.

FINDINGS

In examining the objectives of genetic selection, genetic influence on quality, the roles of public and private plant breeders, variety release, and new technologies for wheat, soybeans, and corn, a number of common findings are evident:

- *Yield v. Quality.*—An inverse relationship exists between yield and quality in all three grains considered. In wheat, corn, and soybeans the trade-off is between protein and yield. Increasing the intrinsic factors that improve quality means that yield usually declines.
- *Objectives in Genetic Selection.*—Yield increase and the agronomic characteristics that relate to yield are the major objectives of plant breeders. Quality is not a high priority in genetic selection but this varies by commodity. The objective in wheat and soybeans is to at least maintain quality while improving yields. But this is difficult to attain. In corn, relatively less attention is given to quality factors while striving to increase yield.
- *Genetic Influence on Quality.*—In general, factors affecting quality are more heritable than factors affecting yield. The potential for improving quality through genetics is therefore high. However, many quality factors are quantitative traits known to be under the influence of a number of genes. This makes the task of enhancing quality more difficult relative to altering a plant's trait influenced by only a few genes. This is further complicated by the fact that genetic alteration (especially with many gene sequences) of one trait frequently leads to undesirable changes in other plant traits.
- *Procedures for Release.*—There are no legally binding procedures for controlling the release of new corn, soybean, and wheat varieties in the United States. Each State develops voluntary variety release policies, and the criteria for release differ by commodity and geographic location. Public and private breeders have yield as their primary criterion and seldom include quality of the harvested grain in their performance tests.
- *Time for Development and Release.*—New crop varieties require approximately 9 to 12 years for development and release. If plant breeding program objectives were to change in 1988, such as aim to develop new varieties with enhanced quality factors, it would be the year 2000 before new varieties were commercially available.
- *New Plant Breeding Technologies.*—Genetic engineering will in the future provide the opportunity for putting a new trait into a plant in a matter of months where it now takes 5 to 7 years to breed into a variety a specific trait. Much of the time is taken up in testing cultivars under farm conditions and in seed increase. These steps must be taken regardless of how a cultivar is produced initially. However, total time from identification of beneficial genes to new plant introduction may be reduced by 4 to 6 years.

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Chapter 7

Technologies Affecting Quality

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Chapter 7

Technologies Affecting Quality

Producers are constrained by the quality characteristics of the seeds available to them, as described in chapter 6. They cannot improve the intrinsic quality of corn, wheat, or soybeans once the seeds are planted. Yet they—and others involved in the distribution of grain—can prevent a deterioration in intrinsic quality and can determine the sanitary and some of the physical quality characteristics. At each step along the way, the technologies applied and the way they are used can prevent, or at least minimize, a loss of quality.

Farmers who run combines too fast, for example, can damage grain, especially as it dries. Grain that is either too dry or too wet when harvested is more susceptible to damage. Precleaning wet grain before it reaches the dryer would improve the quality substantially, yet few dryer operators choose to do this. Breakage during handling produces broken grains and fine materials, which increases storage problems and the risk of infestation by insects or mold. Cleaning and blending—the mixing of two or more grain lots to establish an overall quality—are the focus of many concerns about the declining quality of U.S. grain, and indeed sparked the Grain Improvement Act of 1986.

This chapter therefore looks at these numerous technologies that are applied to grain as it moves from the field to the export elevator or the unloading dock of a domestic food or feed manufacturer. Considered in turn are technologies for harvesting, drying, storing and handling, insect management, transporting, and cleaning and blending. The conditions farmers and handlers should strive for in one situation to maintain and deliver a quality product are not always appropriate in another case. Higher moisture content and temperatures are optimal for minimizing breakage of corn, for example, but not for safe storage. Giving producers enough information to consider all these interactions is one objective of this assessment.

HARVESTING TECHNOLOGIES

Harvesting can be defined as the process by which grains and oilseeds are removed from a plant, gathered, and physically removed from a field. The crop is also threshed (using combines to remove kernels from crop material), separated, and cleaned.

Self-propelled combines of either conventional or rotary design (figures 7-1 and 7-2) harvest nearly all the grain produced in the United States. Rotary combines damage wheat and soybeans less than conventional combines do, although this is not the case for corn. Combine sales have dropped from a yearly average of about 30,000 units during the 1970s to fewer than 1,700 units in 1986. The weak market has slowed new combine development due to cutbacks in research and engineering funds.

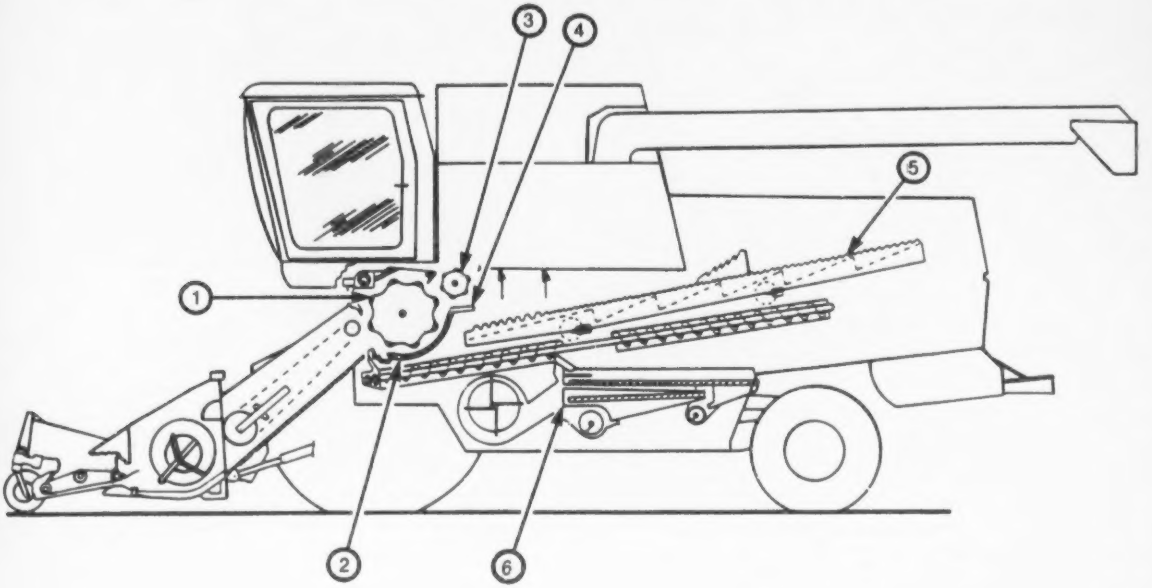
The first workable combine was developed and patented in 1836 (54) for use on small grains. In 1953 two individuals adapted the combine for use on corn, which until then had been harvested by picking the ear. The switch from picking corn by ear to combine shelling/harvesting increased corn production efficiency (52).

Rotary combines were introduced in the mid-1970s. The rotary's ability to use centrifugal separation resulted in fewer moving parts and reduced grain cracking. Today, both designs are used throughout the United States (57).

Current Technologies

Wheat combines differ from those used to harvest corn and soybeans. Conventional combines are built in "grain" or "corn/bean" configurations, with different separation functions in several areas. First, the concave in the corn/

Figure 7-1.—Conventional Combine



Equipped with windrow pickup header: 1—cylinder, 2—concave, 3—beater, 4—beater grate, 5—strawwalkers, and 6—shoe.

SOURCE: G.E. Frehlich et al., John Deere 8820 Titan II Self-Propelled Combine Evaluation Report No. 425, Prairie Agricultural Machinery Institute, Saskatchewan, Canada, 1985.

bean combine has wider gaps than in a wheat combine to allow the larger seeds. The concave transition grate is usually a finger-type unit on corn/bean combines and a cell-type configuration on wheat combines. Second, strawwalkers in corn/bean combines have a louvered bottom design because the rectangular openings in the bottom of wheat strawwalkers are prone to clogging by corn cobs. Finally, the chaffer sieve in corn/bean combines has deeper teeth on the louvers and wider spacing between louvers.

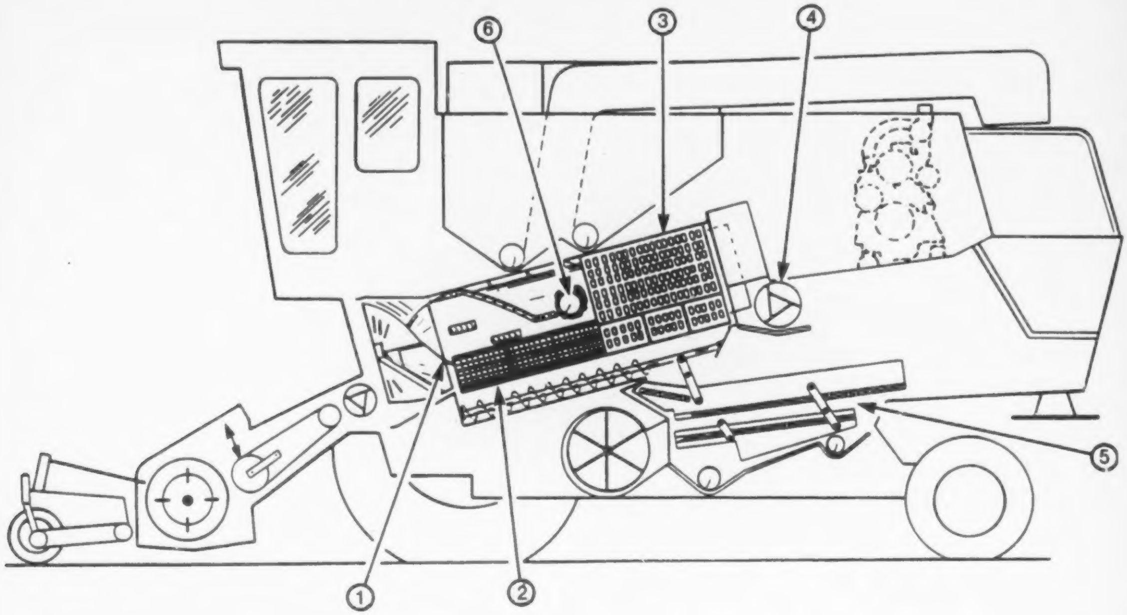
In areas of the United States that grow wheat as well as corn or soybeans, corn/bean combines are often used for harvesting wheat. The extent to which this compromises combine performance is not well documented. The expected impacts would be lower separation capacity and poorer cleaning due to the wide-spaced chaffer and higher cleaning-shoe loads produced by the corn concave.

Conventional self-propelled combines are most common, although variations in the system have been developed to deal with specific problems in certain areas of the country. Two such variations are the practice of windrowing wheat and the development of sidehill and hillside combines.

Windrowers in the Northern Plains States cut the wheat and place it in a swath on top of the wheat stubble, where it is later picked up by a combine equipped with a windrow pickup device (figure 7-1) that offers gentler handling than auger-type headers. Windrowing generally takes place when the wheat is at 30 to 35 percent moisture (54). Although windrowing is an additional expense, it interrupts weed seed development, thereby improving weed control in subsequent years; speeds wheat drying by up to 2 weeks and can shorten combining time considerally; and allows the crop to better withstand hail and high winds.

Combines with leveling in both pitch and roll modes have been developed to accommodate the tilling of 40 to 70 percent slopes in the Pa-

Figure 7-2.—Single-Rotor Rotary Combine



1—Rotor, 2—threshing concaves, 3—separating concaves, 4—rear beater, 5—shoe, and 6—tailings return.

SOURCE: G.E. Frehlich et al., Case IH Self-Propelled Combine Evaluation Report No. 531, Prairie Agriculture Machinery Institute, Saskatchewan, Canada, 1987.

cific Northwest. Such machines are heavily modified production combines with unique suspensions, drive lines, and feeder modifications. Sidehill combines with only roll leveling were developed in the mid-1970s for use on sideslopes of up to 20 percent, and are used primarily on the moderately rolling terrain of the Midwest.

Conditions Affecting Combine Performance

To be competitive, combine manufacturers must achieve an optimal balance between harvest capacity, harvest losses, grain quality, and operator safety and comfort. Combine fuel efficiency is also a concern, but is not the primary factor when designing combines. Conditions such as crop maturity, moisture content, standability, the presence of insects or disease, and the amount of weeds in the field are the main influences on combine performance.

Maturity and Moisture

Physiological maturity occurs when grain has reached its maximum dry weight. Thus, the grain's moisture content at harvest directly affects the amount of kernel damage produced through combining.

Corn maturity is obtained at about 30 to 35 percent moisture. While corn can be harvested at this point, the soft pericarp will de damaged. In the Midwest, harvesting is generally not recommended until the corn has field-dried to 26 percent moisture. In some parts of the United States, such as south Texas, corn field-dries to acceptable moisture levels and is not a problem. In the Northern States, however, obtaining 26 percent moisture is not possible during wet fall harvest periods, and corn must be harvested at higher moisture contents.

It is generally recommended that soybeans not be harvested until they reach 13.5 percent moisture. Soybeans readily absorb moisture overnight and during high humidity periods. After first being field-dried to 13.5 percent, soybeans can be harvested at moistures up to 15.0 percent. Soybeans at 14.4 percent moisture in the morning can easily dry to 11.4 percent by afternoon (11). Soybeans below 12 percent moisture are exceptionally susceptible to shatter loss during harvest.

Weeds

The main factor affecting combine cleaning performance is the amount and type of weeds present in the field at harvest. Weed control is one of the most serious problems facing many U.S. wheat-producing areas and southeastern soybean-producing areas, where a warm wet climate is conducive to weed growth. The amount of weeds affects not only yield, but also the amount of foreign material present in the harvested grain and the combine's ability to remove this material.

Weeds types have a direct bearing on yield and cleanliness. For example, the number of *Hemp sesbainia* in soybean fields has a direct effect on the amount of foreign material in combine samples (45). At 650 plants per acre, 0.8 percent foreign material was found; at 52,270 plants per acre, foreign material increased to 20.3 percent. In weedy fields farmers usually increase cylinder/ rotor speed to force the weed debris through the combine, but this can lead to increased grain damage.

One way to reduce the amount of foreign material in soybeans due to weedy conditions is to reduce the combine's ground speed. It has been found, however, that in weedy fields (compared with weed-free ones) 50 percent or more of the soybean pods are located on the lower 6 inches of the plant. Thus, the combine operator has to cut extra low, which increases the chance of picking up more soil.

Bromus sacalinus (cheat) is a major problem for winter wheat producers in the central Plains. One study found that between 66 and 99 percent of the cheat was introduced into the combine and 41 to 91 percent was delivered to the clean grain bin (18). Several combine modifications have tried to overcome this problem. Three cascade gaps in the cleaning shoe have been introduced in some regions. Other modifications include secondary cleaners and precleaning grain prior to delivering it to the cleaning shoe.

The process of modifying combines to adequately harvest clean wheat from weedy fields has been complicated by the trend toward smaller wheat kernel size, which is a concern because the seeds of most grassy weeds are smaller and lighter than wheat. Thus, the smaller wheat kernel size reduces the margin between wheat and weed size and therefore increases the difficulty of cleaning within the cleaning shoe (57).

Timeliness of Harvest

Timeliness of harvest often takes precedence over other factors such as the optimal moisture content needed for reduced breakage or lower field losses. Everywhere in the United States field conditions will permit harvesting for only a limited number of days. For example, in central Illinois, September and October have had 16 harvesting days in 8 years out of 10, based on statistical weather records (48,65).

Producers must therefore match combine size and the number of combines available to the number of days required to harvest the total acreage. Thus, when combine capacity is not available, long hours must be spent harvesting, which cannot be delayed because of grain moisture. The result of this dilemma is that producers often push the moisture limits, accept higher levels of kernel damage, and do not adjust combines as crop conditions vary.

In spite of the demands placed on the combine for high-capacity harvesting with minimal loss, field harvesting is only part of the total operation. Trucks, wagons, and drivers must be available to provide timely combine-tank unloading. If the crop must be hauled to a grain elevator, long truck lines can slow the harvest. Thus, it is essential to match hauling, drying if needed, and storage capacity with harvesting capacity.

A large percent of the harvest in the Great Plains is accomplished through custom wheat harvesting. The biological ripening of wheat begins in Texas and proceeds up through the Great Plains. This creates the opportunity for combines to follow the harvest. With custom combines concentrated where the crop is ripe, wheat harvest is completed rapidly and the crops' exposure to the elements is lowered.

Combine Adjustments and Operator Proficiency

The combine is the most demanding machine to operate on most farms in terms of operational workload and knowledge required for adjustment and maintenance. Modern combines provides at least 25 adjustments for tailoring the machine to specific conditions. Seven to ten of the most frequent adjustments are accessible from the operator's seat. Operators must constantly monitor ground speed, cutting height, reel speed, and reel height as the machine moves through the field. In addition, crop conditions can demand readjustment within the same field on the same day.

Cylinder/rotor speed can be adjusted by the operator and varies by crop, varieties, and moisture content. Generally, as moisture decreases, threshing speed should also be decreased. Concave settings must always be slightly larger than the size of the grain being threshed. A concave setting that is too narrow causes severe kernel grinding-like damage; if it is set too wide, kernels will be left in the head, on the cob, or in the pod, contributing to high threshing losses.

The extent to which combine operators understand and appreciate the interactions between combine components and adjustments varies widely. Because of the ease by which a nonoptimal cylinder/rotor speed can be confused with an incorrect concave setting, considerable operator experience is required when the goal is to maintain low grain damage and low header, threshing, and separating losses.

Effects of Harvesting Technologies on Grain Quality

The primary quality factors affected by combine harvesting are grain damage (which includes damage to the pericarp, broken kernels, internal cracks, and splits) and cleanliness. Grain damage is linked with threshing and handling components within the combine; cleanliness can be attributed to header height and to separating and cleaning components.

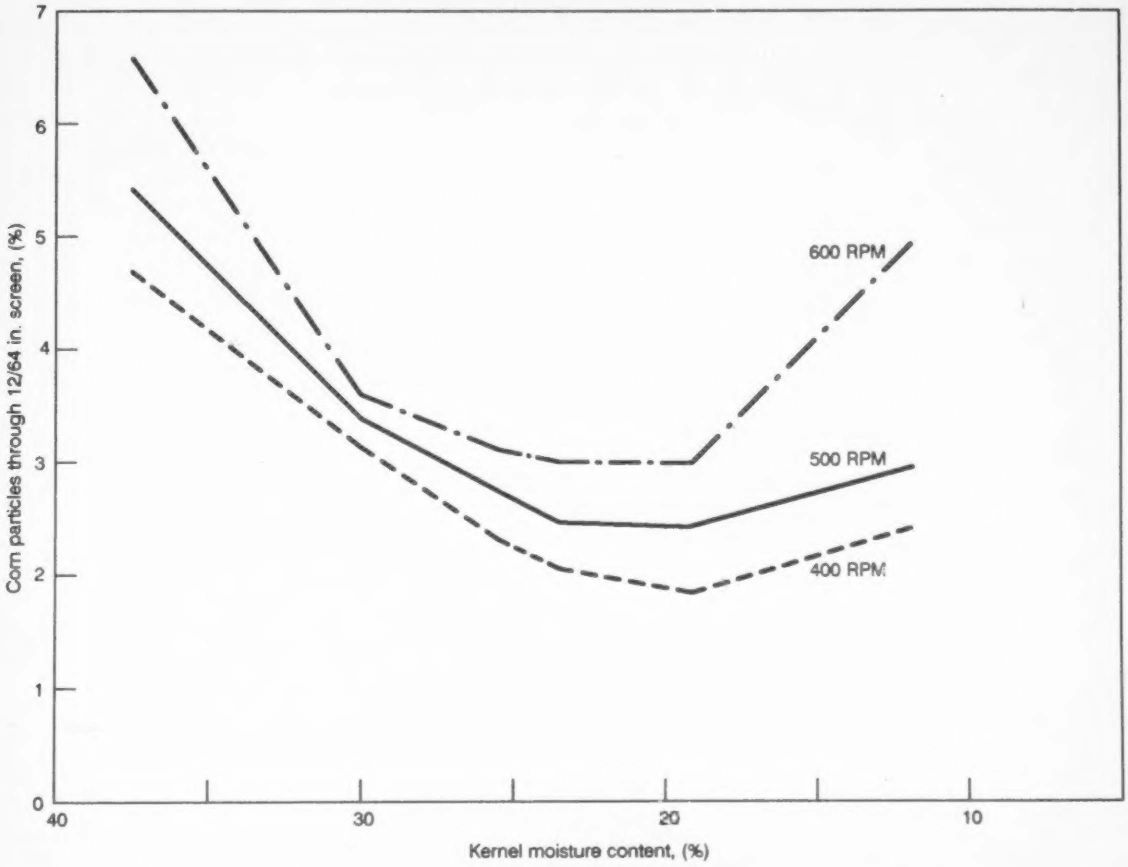
Grain Damage

Cylinder speed, moisture at harvest, and the amount of grain damage are all interrelated. In general, damage occurs whenever grain is harvested. It increases significantly, however, on extremely wet or extremely dry grain. When grain is harvested at high moisture levels, the kernel is soft and pliable. Moist kernels deform easily when a force or impact is applied, and a greater force is needed to thresh wet kernels than dry ones, so they suffer more damage. Drier kernels, however, can break when the same force is applied. Therefore, optimal conditions exist for each grain when cylinder speed and moisture are balanced.

The impact of cylinder/rotor speed on corn breakage varies by moisture level (figure 7-3). As moisture decreases, the impact increases. Breakage is higher at extremely high and low moistures regardless of cylinder/rotor speed. For wheat, the same principles apply: Cylinder/rotor speed increases wheat breakage, and the impact is more pronounced on wheat moistures of 14.6 percent than 18.9 percent. For all grains, cylinder/rotor speed must be reduced at lower moisture levels to minimize grain damage.

The type of combine (rotary or conventional) affects grain damage in wheat and soybeans. Several studies have demonstrated reduced damage from some rotary combines compared with conventional combines. One study on the amount of split soybeans from two types of rotary combines and a conventional combine

Figure 7-3.—Corn Breakage v. Kernel Moisture Content for Laboratory Rasp Bar Sheller Operated at Varying Speeds



SOURCE: G.E. Hall and W.H. Hohnson, "Corn Kernel Crackage Induced by Mechanical Shelling," American Society of Agricultural Engineers 13(1), 1970.

demonstrated the reduced amount of splits using rotary combines (47). Studies on rotary and conventional combines for wheat indicate a two-third reduction in grain damage using rotary combines (57). Studies of corn breakage using the two combine types have not shown any significant differences (52).

Cleanliness

Three combine components directly affect the combine's ability to harvest and deliver clean grain: header height, separating, and cleaning shoe.

Header height must be set to operate near or at ground level. This is particularly true when harvesting certain varieties of soybeans with pods set very low on the stalk. Cutting below the lowest pod or wheat head inadvertently introduces some soil into the combine. Most soil is aspirated out the rear of the combine unless it is about the same size as the kernel. In these cases, soil particles pass through the cleaning sieves with the grain.

Material that is fed onto the cleaning shoe after passing through the cylinder concave or strawwalkers is divided into three streams. Whatever does not move through the top sieve (chaffer) passes out the rear. Grain and other plant parts that pass through the chaffer but not the cleaning sieve are routed back to the cylinder/rotor for rethreshing. Grain that passes through the cleaning sieve is conveyed to the clean grain tank. Aspiration (using fans) is also used in this process to remove light material. If the fans are set too high, grain may be drawn off along with the lighter material.

This process removes material larger than the grain (such as plant parts) and material significantly smaller (like sand and dirt). Sloping terrain, as previously discussed, can affect this process. In wheat, the amount of foreign material increases as the angle of the cleaning shoe decreases (59). Side slopes also create problems since the tendency is for material to congregate on the downhill side of the cleaning shoe.

New and Emerging Technologies

Changes in harvesting technology have been evolutionary rather than revolutionary. For example, the rotary combines were widely publicized as a major breakthrough, yet studies of centrifugal separation had been conducted some 15 years earlier. With declining combine sales over the past 8 years, revolutionary changes are even less likely.

Current harvesting technology provides combines capable of obtaining low grain damage levels and reduced foreign material with acceptable losses. The problem remains in getting operators to run the machines at the lowest grain damage level the combine is capable of delivering. The major advance in this area is through new control systems and automation.

One recent aid for improving harvesting has been the introduction of grain loss monitors. These are mounted behind the combine's separation and cleaning sections and electronically sense the number of kernels that hit a small acoustical pad. Loss monitors have been marketed as a means of reducing threshing and separating losses. They can, however, aid operators in reducing threshing speed until losses become noticeable, thus reducing grain damage. Since grain damage increases as threshing speed rises, cylinder/rotor speed must be reduced as grain dries until threshing losses, observable on the grain loss monitor, start to increase (52).

Information sensors are commonly provided as original equipment on newer combines. Such sensors include digital readout of cylinder/rotor speed, fan speed, feeder shaft speed, reel speed, engine speed, and ground speed. Several manufacturers now have warning lights for speed reductions of the fan, cylinder/rotor, discharge beater, straw chopper, feeder, rear beater, clean grain elevator, and return elevator. When this information is received, operators can now make adjustments from the operator station, but they still must decide if changes are needed.

Low-cost microcomputers and improved sensors mean many of the current operator decisions will soon become automatically controlled by computers. A limited number of computer-assisted programs are already available to assist operators in selecting proper combine settings.

DRYING TECHNOLOGY

Cereal grains and oilseeds are harvested in the United States at moisture levels too high for long-term storage or even short-term storage and transportation within the marketing system. Corn, which is harvested at 20 to 30 percent moisture, must be dried to 14 to 15 percent for safe storage. Wheat and soybean harvest moistures are substantially lower than corn, with safe storage levels marginally lower than harvest moisture. Since wheat (and, in some cases, corn and soybeans) dries naturally in the field in some parts of the country, this discussion mainly concentrates on drying technologies as they relate to corn.

Considerable moisture is removed from grain during drying. When taking corn from 25 to 15.5 percent moisture, 122 kilograms of water are removed per metric ton. Drying grain in the United States takes place on farm as well as off farm in commercial handling facilities using ambient air as the drying medium. On-farm drying systems are usually lower in throughput than off-farm units and frequently employ lower drying-air temperatures.

Dryer design depends on grain type. The requirements for drying-air temperature, airflow rate, and the time the grain remains in the dryer differ for wheat, corn, and soybeans. Drying wheat in a corn dryer without modification will lead to a significant decrease in wheat quality.

It is generally agreed that the bulk of grain quality deterioration happens during drying (6). Too frequently, excessively high-drying-air temperatures and airflows are used to speed the process. This leads to excessive stress cracking in corn and soybeans and degradation in the milling quality of wheat.

On-Farm Drying Systems

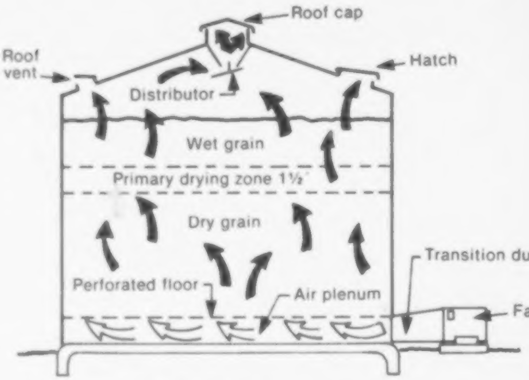
Cereal grains and oilseeds are mainly dried on-farm in the United States. Indiana is typical: In 1984, less than 5 percent of the States's corn was dried off-farm (37). On-farm systems fall into three broad categories: bin dryers, nonbin dryers, and combination systems.

Bin Dryers

Bin dryer systems include: 1) in-bin natural air, 2) in-bin low temperature, 3) solar, 4) in-bin storage layer, 5) in-bin counter-flow, and 6) batch-in-bin. They all use a bin to hold wet grain as it is dried. The drying-air temperatures of the first four systems are relatively low, while the last two need temperatures as high as 70 °C.

In-bin natural air, low temperature, and solar drying systems are similar (figures 7-4). Wet grain is placed in a bin to a depth of 2.5 to 5.0 meters and slowly dried using an external fan as the airflow source. Each system can produce high-quality grain. However, minimum airflow rates are critical for their success; these depend on the initial moisture content, harvest date, and environmental conditions. Airflow rates vary by location and, consequently, farmers need considerable expertise to operate these systems properly by selecting the correct airflow rate. Slower drying than the required rate can lead to grain molding before safe storage levels are reached.

Figure 7-4.—In-Bin Natural-Air Grain Drying System



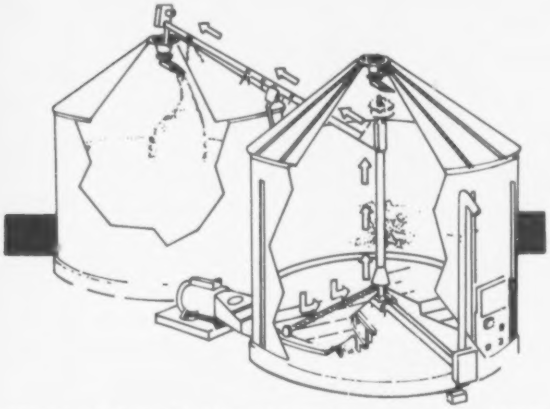
SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

In-bin storage layer drying differs slightly from natural air drying. Rather than filling a bin all at once with wet grain, successive layers are placed in the bin after the preceding one has almost reached the desired moisture content. Like natural air drying, this drying system has low capacity, requires considerable operator expertise, is energy-efficient, and can produce excellent quality grain when operated properly.

In-bin counter-flow drying is relatively new and consists of two bins (figure 7-5). One is a heated air in-bin counter-flow dryer and the other is a natural air in-bin dryer and cooler. Wet grain is loaded into the first bin and dried until the bottom 10 centimeters has reached 16 to 18 percent moisture. The partially dried, hot grain is then moved to a second bin for slow final drying and cooling. The automatic nature of this process, along with the ability to produce quality grain at fairly high capacities, has contributed to the commercial success of in-bin counter-flow dryers.

Batch-in-bin dryers differ from in-bin counter-flow dryers in that they lack the second dry-

Figure 7-5.—In-bin Counterflow Grain Dryer



SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

ing and cooling bin. Airflow rates and drying temperature are similar, but the energy efficiency as well as the grain quality characteristics are poorer (4).

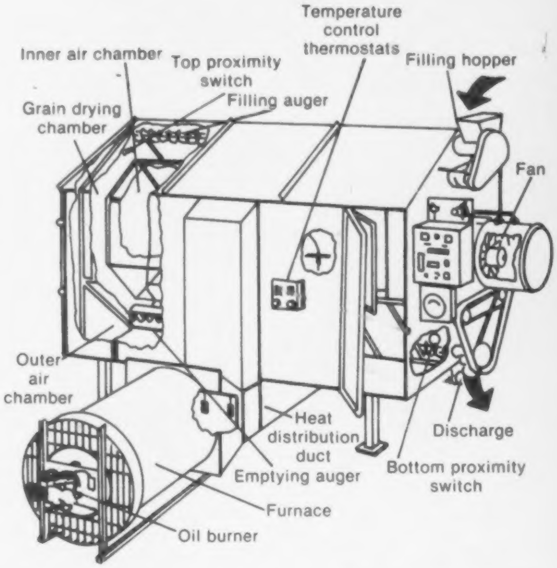
Non-bin Dryers

Non-bin dryers are either portable batch or continuous-flow dryers. Over half the U.S. grain crop is dried (both on and off farm) in these two types (6). They utilize drying air temperatures in excess of 100 °C or more and airflow rates over 110 cubic meters per minute per ton. Thus, the drying rate is high, but the resulting grain quality is often lower.

Portable batch dryers consist of a plenum surrounded by a 30 to 40 centimeter grain column (figure 7-6). Hot air traverses the grain layer quickly and in the process overheats and overdries part of the grain column. The batch is removed from the dryer as soon as the desired final moisture content and temperature are reached. A portable batch dryer is comparable to in-bin batch dryers except that grain is dried at higher temperatures and airflow rates due to the reduced depth of the grain layer.

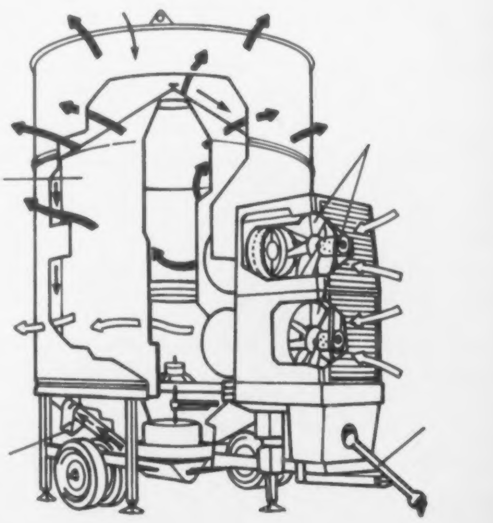
Continuous-flow dryers are predominantly of the crossflow type (figure 7-7). The drying air flows perpendicular to the grain flow through the dryer. The plenum/grain column

Figure 7-6.—Portable Batch Grain Dryer


Temperature control thermostats
Inner air chamber
Top proximity switch
Filling hopper
Filling auger
Grain drying chamber
Fan
Outer air chamber
Heat distribution duct
Discharge
Emptying auger
Bottom proximity switch
Furnace
Oil burner

SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

Figure 7-7.—Continuous-flow Crossflow Grain Dryer



SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

is similar to that in a portable batch dryer. Cooling takes place in the bottom one-third of the drying column. Airflow rates and drying temperatures are the same for both types; the only difference is the grain velocity.

Continuous-flow crossflow dryers do not dry grain uniformly because a large moisture gradient exists across the grain column when drying is discontinued. During the cooling cycle, the degree of nonuniformity decreases, but a definite moisture differential among kernels still exists when the grain leaves the dryer. In one study, when drying 25 percent corn at 110 °C to 16 percent average moisture, the corn's moisture content at the air inlet side of the grain column reached 8 percent. At the air outlet side, the grain was still at 22 percent, thus creating a moisture gradient of 14 percent (24). As table 7-1 indicates, part of the grain in a crossflow dryer approaches the drying-air temperature, which results in overdrying and sharp increases in breakage.

Combination Drying

Combination drying is a system in which high-temperature, high-speed batch or continuous-flow drying is followed by low-temperature, slower in-bin drying and cooling. This attempts to maximize the advantages and minimize the disadvantages of the two systems.

Combination drying is mainly used for corn. When corn is harvested in the 22 to 35 percent range, it is dried in a high-temperature dryer to an intermediate moisture content of 18 to 24 percent and then moved hot to an in-bin dryer and slowly final dried and cooled. The in-bin dryer usually is a natural air dryer. The best known type of combination drying is dryeration (figure 7-8). The two main advantages of combination drying over non-bin dryers are the increased energy efficiency and improved grain quality.

Table 7-1.—Grain Temperature, Moisture Content, and Breakage Susceptibility at Different Locations in the Grain Column of a Crossflow Dryer

Distance from air inlet (cm)	Grain temperature (°C)	Moisture content (in percent)	Breakage susceptibility (in percent)
1.25	102	10	48
7.50	78	20	11
13.75	51	24	10

SOURCE: R.J. Gustafson et al., "Study of Efficiency and Quality Variations for Crossflow Drying of Corn," ASAE Paper No. 81-3013, 1981.

Off-Farm Drying Systems

Grain dryers located off farm in commercial handling facilities are non-bin continuous-flow models. Three types are currently in use: crossflow, mixed flow, and concurrent flow.

Crossflow

Crossflow dryer design was discussed in the on-farm section. The distinguishing feature here too is the perpendicular direction of the grain and airflows, which results in nonuniform drying. Recent design improvements for off-farm crossflow dryers have improved grain quality and energy efficiency.

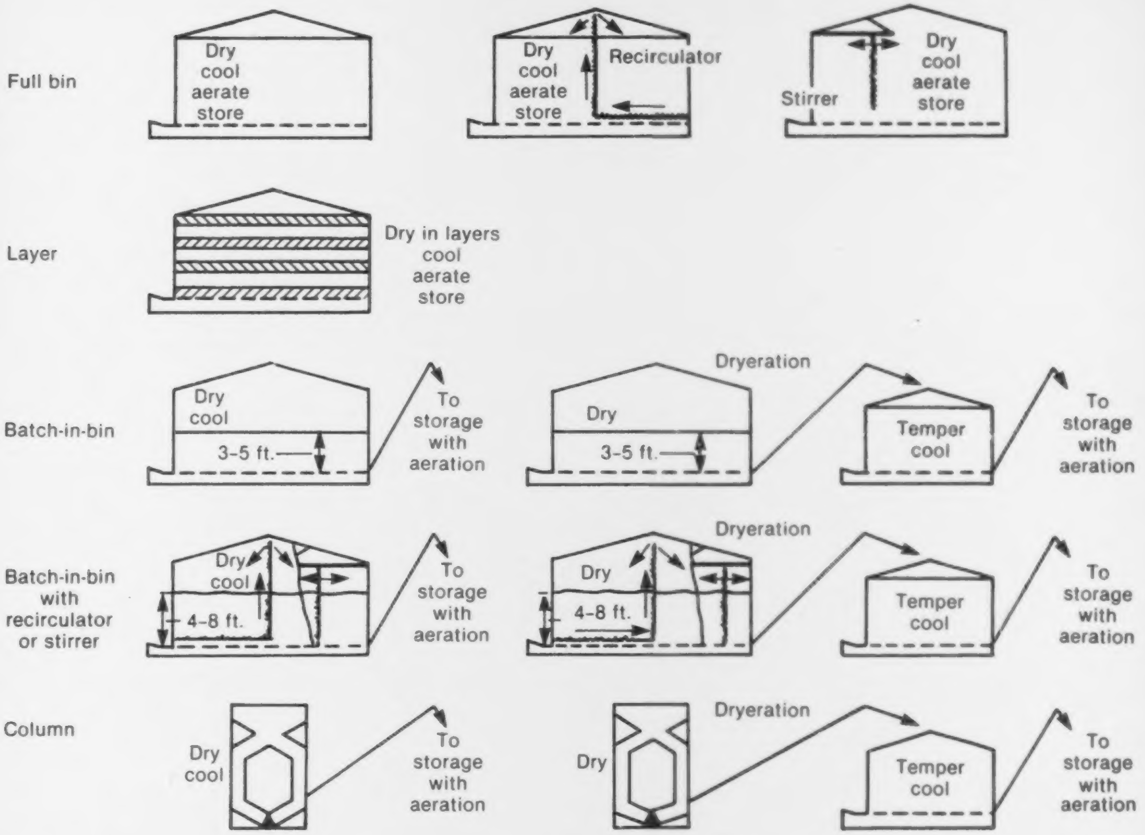
In a conventional crossflow dryer, the discharged air is only partly saturated. Recycling part of the drying air and all of the cooling air greatly decreases energy requirements. Along with air recycling, airflow reversal has been incorporated in some crossflow dryers in order to offset the large moisture differential in the grain column. Placing a grain inverter in the grain column is less expensive, but also less effective. Grain inverters turn the overheated grain at the air inlet side to the air exhaust side of the column and thus minimize overheating (50). Crossflow dryers without air reversal or grain inverters have moisture gradients across the drying column as large as 20 percent and grain breakage as high as 50 percent (24).

Two new features added recently to the basic crossflow design—differential grain speed and tempering—improve grain quality (40). A crossflow dryer incorporating air recycling, air reversal, differential grain speed, and tempering is commercially available, but its high initial cost is preventing general acceptance.

Mixed Flow

Mixed-flow dryers are also called cascade or rack-type dryers. Grain is dried by a mixture of crossflow, concurrent flow, and counterflow

Figure 7-8.—Dryeration Grain Drying Systems


Full bin
Dry
cool
aerate
store
Dry
cool
aerate
store
Recirculator
Stirrer
Dry
cool
aerate
store
Layer
Dry in layers
cool
aerate
store
Batch-in-bin
Dry
cool
3-5 ft.
To
storage
with
aeration
Dryeration
Dry
3-5 ft.
Temper
cool
To
storage
with
aeration
Batch-in-bin
with
recirculator
or stirrer
Dry
cool
4-8 ft.
To
storage
with
aeration
Dryeration
Dry
4-8 ft.
Temper
cool
To
storage
with
aeration
Column
Dry
cool
To
storage
with
aeration
Dryeration
Dry
Temper
cool
To
storage
with
aeration

SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

drying processes. The grain flows over a series of alternate inlet and exhaust air ducts. This results in fairly uniform drying and therefore a relatively uniform moisture content and quality. The drying temperature in mixed-flow dryers is higher than in crossflow ones because the grain is not subjected to the high temperature for as long.

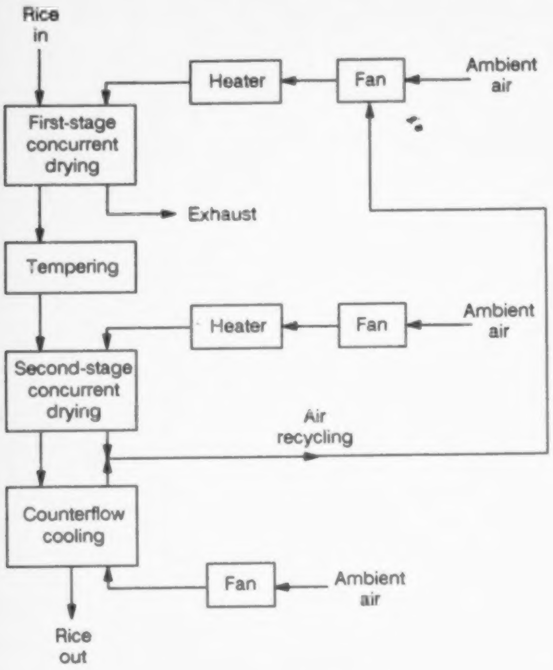
Mixed-flow dryers are more expensive to manufacture and require more extensive air pollution equipment. For these reasons, the number of mixed-flow dryer manufacturers has decreased in the United States. In other countries, mixed-flow dryers remain the predominant large continuous-flow dryer (6).

Concurrent Flow

In concurrent-flow dryers the grain and drying air flow in the same direction (vertically). Cooling occurs in a concurrent-flow cooler in which the grain and air flow in the opposite direction. Commercial concurrent-flow dryers consist of two or three concurrent-flow drying zones and one counterflow cooler (figure 7-9).

The most distinguishing feature of these dryers is the uniformity of the process. Every kernel undergoes the same heating/drying/cooling process, unlike in crossflow and mixed-flow dryers. The drying-air temperature is much higher than in other dryers because the wet grain is subjected to the hot drying air not for

Figure 7-9.—Two-Stage Concurrent-Flow Grain Dryer With Counterflow Cooler and One Tempering Zone



SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

hours (crossflow dryers), or minutes (mixed-flow dryers), but only seconds. Thus, the grain does not approach the temperature of the drying air, as it does in other types.

The uniform, relatively gentle grain drying and cooling in concurrent-flow dryers results in dried grain of superior quality (table 7-2). Breakage susceptibility in concurrent-flow dryers is half that of mixed-flow and one-fourth that of crossflow dried corn.

Conditions Affecting Dryer Performance

Dryer performance is affected by physical, biological, economic, and human factors. Each can have an impact on grain quality.

Physical Factors

The physical factors affecting drying performance are climate and weather. The climate determines the type of hybrids that can be grown in a particular region, the expected moisture content range, and the weather at harvest. Initial grain moisture entering a dryer has a significant effect on dryer performance. Not only are dryer capacity, energy consumption, and operating costs influenced by the initial moisture, so is grain quality. When grain is harvested above or below its optimum harvest moisture, quality losses during drying increase (12). Thus, in Northern States, where harvest moistures frequently exceed optimum value, corn and soybean quality is inherently inferior to that of grains grown, harvested, and dried in the Central Corn Belt States.

Certain years will be wet in the summer and fall and result in grain with excessively high moisture content reaching the dryers. This leads to lower dryer capacity, higher energy consumption, higher drying cost, and decreased grain quality. Weather conditions have a direct effect on the performance of some on-farm bin dryers. These low-capacity systems may not be able to dry wet grain before molding sets in (58). Off-farm systems are less directly affected by weather conditions.

Biological Factors

Two biological factors affect dryer performance: grain type and genotype. First, wheat dries most rapidly and corn most slowly. A concurrent-flow dryer has a 23 percent higher throughput for wheat than for corn while operating at the same drying temperature. The maximum drying temperature for corn is substantially higher than that for wheat, thus affecting the quality of these two grains differently. Also, energy use is affected by grain type.

Genotype determines the drying rate of single corn kernels (64). Some genotypes dry slowly and others dry fast. Dryer capacity and fuel efficiency are higher with new genotypes. Drying rates for wheat and soybeans, however,

Table 7-2.—The Effect of Dryer Type on the Drying-Air Temperature, the Maximum Grain Temperature, and the Breakage Susceptibility of Corn

Dryer type	Drying-air temperature (°C)	Maximum grain temperature (°C)	Breakage susceptibility (percent)
Crossflow	80-110	80-110	20
Mixed-flow	100-130	70-100	10
Concurrent-flow	175-285	60-80	5

SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

are not influenced by genotype (46). Breakage susceptibility after drying also varies by genotype (51,63). Table 7-3 shows that a fivefold increase in breakage susceptibility may occur when switching genotype.

Economic Factors

Economics can affect dryer performance by influencing fuel prices and availability. The relative price of natural gas, fuel oil, liquid propane, and electricity varies from year to year. At the present time, natural gas is the least expensive and electricity the most expensive energy source in the United States. The type used affects dryer operation because it influences burner efficiency and drying-air quality.

Grain dryers are directly heated in the United States, while indirect heating grain drying systems are common elsewhere. Indirect heating uses heat exchangers and is less energy-efficient, more costly, and less grain polluting than direct heating. It is used to prevent absorption by the grain of polycyclic aromatic hydrocarbons contained in the drying air. Of the three fossil fuels commonly used in direct-heated dryers in the United States, only fuel oil causes hydrocarbon absorption by grain (35).

Table 7-3.—Breakage Susceptibility of Different Corn Genotypes

Genotype	Breakage susceptibility (percent)
FRB 73 x FR 18	23.5
FRB 73 x PA 91	10.5
FRB 73 x FR Mo 17	7.5
FR Mo 17 x Fr 634	4.3

SOURCE: M.R. Paulsen, "Corn Breakage Susceptibility as a Function of Moisture Content," ASAE Paper No. 83-3078, 1983.

Human Factors

Grain drying is a complicated heat/mass/momentum transfer process of a heat-sensitive biological product and is frequently not well understood by the average dryer operator. At most commercial handling facilities, the dryer operator job is seasonal: It requires 12-hour days, 7 days a week, for 2 to 3 months. The pay rate is marginal and job training is usually by trial and error. Therefore, it is not surprising that dryer maintenance, supervision, and operation are far from optimal. All these factors affect the performance of the typical dryer with respect to capacity, energy efficiency, and grain quality (5). The most frequent mistake is using excessively high temperatures in order to increase dryer capacity.

Auxiliary Factors

Several auxiliary equipment (instrumentation) items influence grain dryer performance. Included here are the grain moisture meter, the air temperature meter, and the dryer controller.

Moisture meters are an integral part of the grain drying system. Electronic meters are used at grain handling facilities. Meters commercially available have an accuracy of ±1 percent at the 13 to 16 percent moisture range and ±2.5 percent at higher moistures (34). This contributes substantially to overdrying or underdrying of grain.

Air temperature measurement in a grain dryer is usually accomplished by a single thermocouple or thermistor, an acceptable practice when the temperature distribution in the dryer plenum is uniform. This is not the case, however, in many off-farm dryers (2) or on-farm models (58). Temperature differences of 20 to 35 °C in the plenum are not uncommon, resulting in overheating of part of the grain column and deterioration of average grain quality.

Controlling dryers is usually manual, and overdrying is frequently the result. Automatic control systems have recently become commercially available for in-bin and continuous-flow grain dryers. Their use leads to savings in energy and drying costs and limits the degree of overdrying and grain quality deterioration.

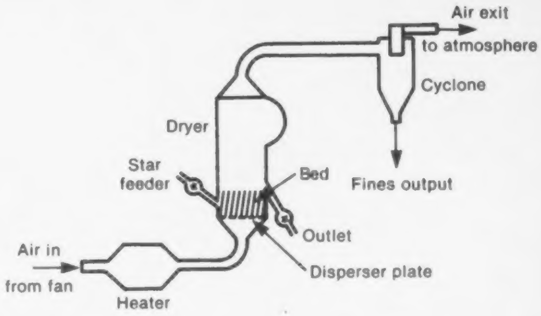
New and Emerging Technologies

Some new and emerging drying technologies have the potential for a significant impact on overall grain quality, especially in corn. Combination drying has already been discussed, along with its ability to improve corn quality at the farm level. Although the procedure has been known for a decade, it is still used only sparingly because of the more demanding logistics and additional grain-handling equipment required. No other promising technology appears to be on the horizon for on-farm grain drying.

Mixed-flow and concurrent-flow drying are off-farm drying technologies that produce higher quality grain than the standard crossflow dryers do. Both dryer types are commercially available in the United States. Their high initial cost (10 to 20 percent more than comparable crossflow dryers) has thus far prevented their widespread use. The same can be said for automatic moisture controllers. If the payback period of these technologies can be shortened, rapid market penetration can be expected (6).

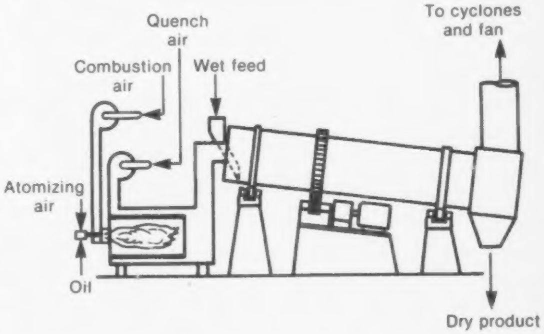
Two off-farm systems not used in the United States for corn are the fluidized-bed dryer and the cascading-rotary dryer (figures 7-10 and 7-11). A fluidized-bed grain dryer was at one time commercially available in the United States, but production was discontinued due to high electricity costs and excessive air pollution. The cascading rotary dryer is used in the United States to dry parboiled rice. High initial and maintenance costs plus high energy consumption characterize the U.S. rotary dryer design.

Figure 7-10.—Fluidized-Bed Grain Dryer



SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

Figure 7-11.—Cascading-Rotary Grain Dryer



SOURCE: F.W. Bakker-Arkema, "Grain Drying Technology," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

At least two companies have experimented with microwave grain dryers, but both have marketed commercial models without success. The advantages of low energy consumption and high grain quality were offset by high initial cost and low product throughput. It is unlikely that microwave grain dryers can compete with conventional drying techniques as long as the economic return of improved grain quality remains low.

A technology that could aid the drying rate of corn is the use of ethyl oleate and ethyl oleate/ethyl sterate mixture. Small-scale preliminary tests show that these chemicals applied to high moisture corn significantly increase the drying rate. The National Corn Growers Association is coordinating a series of larger scale tests of the chemicals at several universities.

STORAGE AND HANDLING TECHNOLOGIES

The usual surplus of U.S. grain means storage is required for longer and longer periods. With the increasingly large carryovers and the necessity to store more grain for more time, grain could be stored for a year or longer. Grain is a perishable commodity with a finite shelf life. Storage can only extend that shelf life, not improve it.

The total U.S. grain storage capacity in 1987 was about 23 billion bushels. Of this 14 billion are located on farm, and the other 9 billion off farm (56). Illinois leads in off-farm capacity, followed by Iowa, Kansas, Texas, and Nebraska (1). These States account for 53 percent of all off-farm storage. The number of off-farm storage facilities totaled 13,873 on December 1, 1987. Smaller proportions of wheat and soybeans are stored on farms (31 percent for wheat and 25 percent for soybeans) than of corn (47 percent). Major wheat-producing States in the Southern Plains tend to have more wheat stored off farm in commercial facilities than the Northern Plains States. Over 80 percent of the corn and soybean inventories are stored in the major corn- and soybean-producing States.

Current Technologies

Grain is stored in buildings or piles for future marketing and in transportation modes en route to destination. A wide variety of sizes and types of structures are used. The basic storage types can be classified as upright concrete or metal bins (vertical storage), buildings (horizontal or flat storage), and onground piles. The handling equipment used in each type is similar.

Handling Equipment

Handling equipment can be broken down into two categories, based on grain movement direction: vertical or horizontal (56).

The belt bucket elevator using an elevator leg is the primary means of moving grain vertically in commercial grain facilities. The leg consists of a vertical endless belt with buckets spaced evenly all along it. The buckets are filled by scooping up the grain at the bottom (boot) of the leg. Grain is discharged at the top by centrifugal force as the buckets pass over the top (head) pulley. Recent elevator designs have eliminated the need for traditional elevator legs by introducing incline belts to move grain vertically. After discharge, the grain flows by gravity through spouting or horizontally by belts or other conveying devices.

Commercial elevators using elevator legs or incline belts are available in any size and capacity to meet the vertical lift requirements of both large and small facilities. Elevators using legs can operate relatively economically at less than their rated capacity, unlike some other grain-handling devices. There is no problem with increased grain breakage resulting from legs being used at less than rated capacity. The amount of grain breakage occurring in elevators using legs is affected by the type and size of the buckets, belt velocity, and transfer loading of the buckets. Overloading the buckets causes spillage and can increase kernel breakage.

Loading grain on the up side of the leg causes more damage than loading on the down side (20), which should be a consideration for elevators handling corn. For wheat, no difference can be detected as long as the leg is operated at normal speed.

Belt conveyors are the primary means of moving grain horizontally in most commercial facilities and, as mentioned, are becoming increasing popular for vertical lifting. They consist of an endless belt supported by rollers and driven by a shaft-mounted speed reducer motor. They are usually open, but may be covered when used outside a building. Belt width varies and can be operated at 500 to 550 feet per minute. Conveyors can be inclined up to 15°, but should be horizontal at the point of loading. They can accommodate a wide range of speed or volume demands, are energy-efficient, and have relatively low maintenance and operating costs. Grain breakage is minimal when moved this way. Most belt conveyors are used in fixed installations, but portable inclined models are available for use in loading flat storages.

Other types of conveying equipment include drag flight, screw auger, and pneumatic conveyors. Drag flight conveyors are enclosed tubes in which a chain with paddles or flights moves. The chain is driven by a shaft and sprocket in the head discharge section with an idler shaft and sprocket in the tail section to maintain tension on the chain. As the flighting moves, it carries grain along with it.

Drag conveyors are available in a wide range of sizes and capacities and as fixed or portable models. They are relatively inexpensive, easy to load, move grain at low velocities, and require less space than conventional belt conveyors. Since they are enclosed, they are subject to higher levels of insect infestation than belt conveyors are. The demand for low-cost conveyors has resulted in a substantial increase in the use of drag conveyors.

Screw auger conveyors have for many years been the principal means of moving grain on farm or where inexpensive portable equipment is needed. They consist of a round tube with a continuous spiral or screw inside and can be powered by farm tractors or electric motors. They are space-efficient and portable, and can move grain horizontally or at relatively steep angles. On the negative side, they have high power requirements and can cause considerable grain breakage, depending on the design and operation of the auger.

Pneumatic conveying is a system that moves grain by air inside a pipe. The air-moving device must be able to provide the air velocity and sufficient pressure to overcome the airflow resistance and the resistance of the grain to flow through the system. Pneumatic system capacity is a function of conveyor size, power supplied, and the vertical or horizontal conveying distance. Pneumatic conveying normally requires more power than bucket legs. Factors that increase grain breakage include air velocities, poor pipe joint connections, and overloading the air-lock feeders. As with other handling equipment, breakage is not as great a concern for wheat as for corn. Pneumatic systems are not widely used in commercial facilities mainly because of the high energy input and power cost.

Storage Types

The most common and easily managed storage type is upright concrete or metal bins (32). Bin sizes can range from as little as 3,000 bushel farm bins to over 500,000 bushel bins at commercial facilities. Upright bins are generally filled from the top and unloaded from the bottom by gravity flow. Bins can be various heights, with deep concrete bins ranging from 98 to 164 feet. The bottoms can be flat or constructed with hoppers. Flat bin bottoms require the manual removal of grain left over after gravity flow has ceased. Most commercial bins have hopper bottoms that allow complete grain removal without assistance. Configurations can range from one or more individual farm bins to a multitude of bins tied together with handling equipment in commercial facilities.

Horizontal systems have long been used for extended storage. These buildings may be constructed of metal, wood, concrete, or any combination of these materials. Horizontal storages usually have flat floors and are filled from conveyors in the roof or by portable incline belts. The grain is removed by conveyor tunnels in the floor and manual movement with front-end loaders. Movement into and out of these buildings is very labor-intensive. Grain depth is lower in horizontal storage than in most upright commercial bins. Storing grain in large buildings creates additional problems in that the large roof area increases the risks of water leaks. These types of structures can stand alone or be tied in with upright bins in commercial facilities.

Grain can also be placed in piles directly on the ground or on pads and can be either covered (usually with a vinyl tarp that provides some protection from the elements) or left uncovered. Piles can be contained by fixed or movable sloping walls or circular rings. Any type of onground pile is difficult to load and unload and is very labor-intensive.

Quality Problems That Arise During Storage

Grain quality can be compromised by physical damage during handling and by biological agents (mold and insects) during storage. Grain damage during handling stems from breakage, which produces broken grains and fine materials. Storage problems increase when this happens, and damage from molds and insects is more likely to occur with higher amounts of these materials.

Insects create numerous problems in stored grain:

- economic losses because of the amount of grain consumed,
- wastes left behind in the grain,
- insect fragments in finished products, and
- grain heating.

Insects' metabolic processes can raise grain temperatures and moisture to ideal conditions for mold growth. In addition, another problem arises from the residues of pesticides used to control insects. (Insect control is covered in the next section of this chapter.)

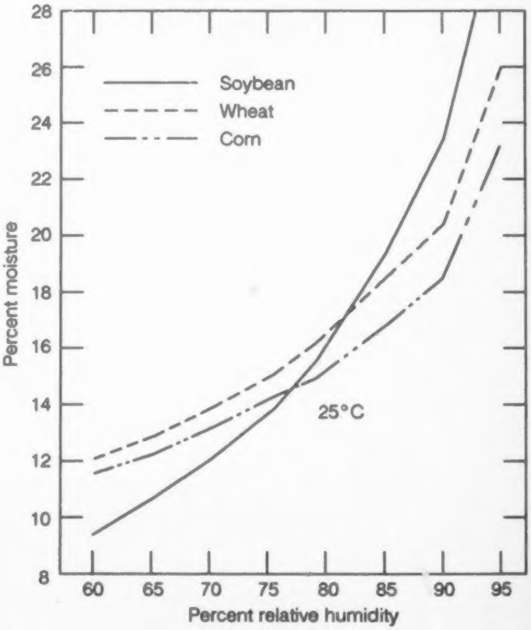
When molds grow they produce heat, moisture, and carbon dioxide. The heat and moisture provide even better growing conditions and the molds proliferate. Molds are parasites that obtain their sustenance from the grain they grow on. Grain quality is affected in that mold growth creates damaged kernels, deposits toxic substances, and creates a loss in dry matter, with accompanying decreases in density.

Interactions between moisture, temperature, and relative humidity spurs mold growth and increases insect activity. Basically, a grain moisture in equilibrium with 65 percent relative humidity will support mold activity. Different grains will create the optimum relative humidity at different moisture levels, which is why soybeans cannot be stored at the same moisture content as corn (figure 7-12).

Many fungi species can develop in stored grain and each has its own requirements for growth. *Aspergillus flavus* is a prime example in corn. This species produces aflatoxins when humidity is at 75 to 85 percent (15). Other species grow at lower humidities and temperatures. Fungi are more sensitive to moisture content than to temperature, with some species still active at near-freezing temperatures but high humidities.

Additional biochemical changes accompany damage from mold and insect invasion. A linear relationship has been established between free fatty acid content in soybeans and damage (38). In wheat, heating grain destroys glu-

Figure 7-12.—Moisture, Temperature, and Relative Humidity Interactions



SOURCE: Office of Technology Assessment, 1989.

ten protein functionality. Damaged kernels may or may not reduce feed value per unit of weight; studies have reported varying results. Moldy kernels have a greater risk of containing one or more toxins.

Moisture weight is lost during routine aeration. Also, when grain spoils, it heats, and the heat liberated is capable of evaporating additional water. Investigations suggest that as damaged kernels increase, additional weight is lost. Kernel weight and density also reflect loss in dry matter. One study reported a 1 to 2 pound test weight loss in the entire grain mass from typical insect infestation (61).

Increases in damaged kernels and reductions in test weight are exponentially related to grain moisture and temperature (60). This research led to development of an Allowable Storage Time Table for corn (table 7-4). At the end of the Allowable Storage Time, corn will be on the verge of dropping one grade as defined by the U.S. Standards for Corn and will have lost about 0.5 percent of its original dry matter weight.

Neither grain temperature nor the moisture content of a spoiling mass remain constant over time (15). Other recent studies show that mold toxins can be produced before the Allowable Storage Time is reached. Extensive work to develop an Allowable Storage Time Table for wheat and soybeans has not been done. However, the basic principles are the same; the only differences would be the moisture content and number of days.

Storage Techniques That Protect Grain Quality

Controlling Breakage

Research has shown that breakage during handling is more significant in corn than in wheat and soybeans (43). Drop height in free-fall and spouting tests were found to be the most significant variables, with the largest amount of breakage occurring when dropping grain against a hard surface. Higher moisture content and temperatures are the best conditions for minimizing breakage, but these are not optimal for safe storage.

The National Grain and Feed Association has found that "repeated handlings showed that the amount of breakage was cumulative and remained constant each time grain was handled or dropped: This was found true whether or not the broken material was removed from the test lot before subsequent handling" (43). It also found that belt speed in bucket elevators has no measurable effect on grain damage, but grain thrower tests show breakage increased with increased belt speed. Tests for impacts showed slightly less breakage against wooden bulk heads than against steel ones. Grain breakage was also found to increase in screw conveyors not operated at full capacity. Three factors must be controlled to reduce the amount of breakage:

1. velocity,
2. repeated handlings, and
3. impact surface.

Table 7-4.—Allowable Storage Time for Corn

	Corn moisture (percent)						
Grain temperature (°F)	18	20	22	24	26	28	30
	days in storage						
30	648	321	190	127	94	74	61
35	432	214	126	85	62	49	40
40	288	142	84	56	41	32	27
45	192	95	56	37	27	21	18
50	128	63	37	25	18	14	12
55	85	42	25	16	12	9	8
60	56	28	17	11	8	7	5
65	42	21	13	8	6	5	4
70	31	16	9	6	5	4	3
75	23	12	7	5	4	3	2
80	17	9	5	4	3	2	2

SOURCE: Midwest Plan Service, "Low Temperature and Solar Grain Drying," Iowa State University, Ames, IA, 1980.

Grain velocity is considered the most important factor to be controlled (table 7-5).

Monitoring Moisture Content

Molds will grow on any kernel or group of kernels that provide the right conditions. Moisture content and uniformity within storage facilities is therefore critical to maintaining grain quality. As demonstrated by the Allowable Storage Time Table for corn, knowledge of the moisture content is a key element in determining storability. Moisture uniformity within a storage facility, on the other hand, is subject to the limitations of measurement equipment and the ability to segregate differing moisture levels within the facility.

Moisture meter accuracy was discussed in the drying technologies section of this chapter. The meters provide average readings, but moisture levels within a grain sample can vary greatly. This can lead to false assumptions and hamper appropriate actions based on the average moisture reading, especially when handling nonuniformly dried corn that has been blended with high and low moisture levels and when handling freshly harvested corn. The problem is compounded by the fact that the moisture content of corn kernels on one ear can vary from 1 to 4 percent. Also, moisture will never fully equalize. If the spread from high to low is 4 percent, moisture will equalize within 1 percent (49). The net result is that moisture variation in a grain sample cannot be detected and the diversity of moisture being placed into storage cannot be controlled.

Nonuniform moisture levels in a storage facility can also be a function of the number and size of storages available. Segregating differing moisture levels in horizontal or pile storage is difficult, and several different moisture levels are often comingled. Large upright bins predominate in some corn- and soybean-producing areas. Depending on the number and size of bins available, and on the moisture levels being stored, differing moisture levels must be comingled.

Table 7-5.—Relative Amounts of Breakage for Grains Tested Under Four Handling Conditions

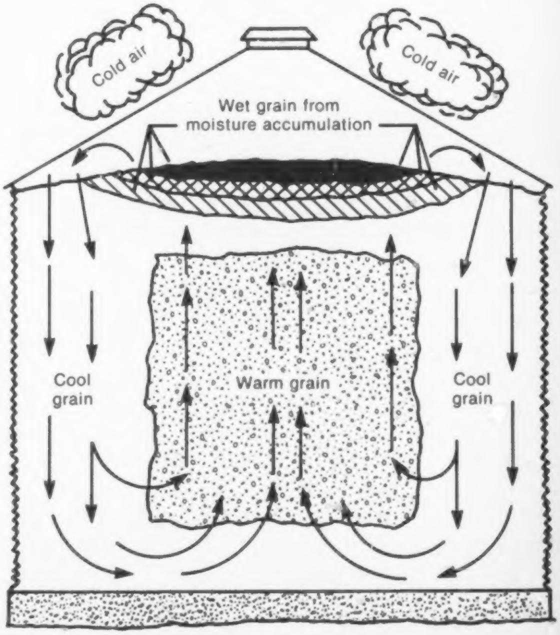
	Percentage of grain breakage caused by:			
Grain	Free-fall drop	Spouting drop	Grain thrower	Bucket elevator
Corn	6.3	3.2	1.6	1.1
Soybean	2.0	1.0	0.7	0.3
Wheat	0.2	0.15	0.2	0.1

SOURCE: J.E. Maness, "Maintain Grain Quality Through Good Handling Practice," National Grain and Feed Association, Washington, DC, 1976.

Moisture content in any one particular location within a storage facility is subjected to the moisture/temperature/humidity relationship. Nonuniform moisture levels can lead to spoilage in localized areas within storage (14,17). These locations are commonly referred to as hot spots; if left unattended, they can spread to the entire grain mass.

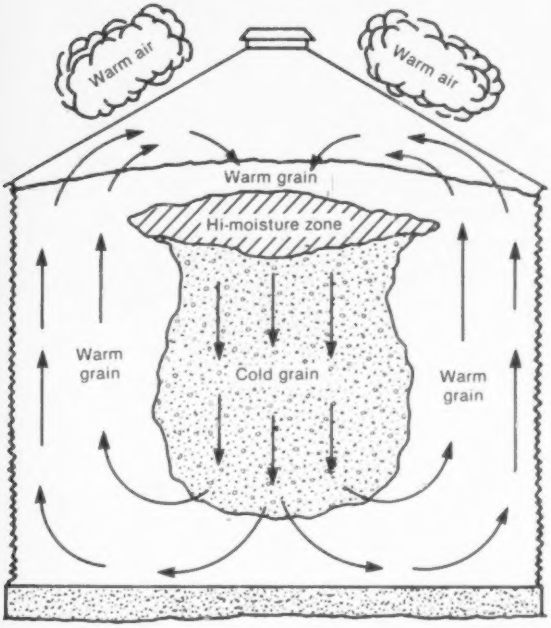
Even assuming that moisture and temperature are uniform within a grain mass, they will not remain so over time, as noted earlier. Moisture will migrate in response to temperature differentials (figures 7-13 and 7-14). When the

Figure 7-13.—Moisture Migration Patterns in Falling Temperatures



SOURCE: G.H. Foster and J.L. Tuite, "Aeration and Stored Grain Management," in *Storage of Cereal Grains and Their Products* (St. Paul, MN: American Association of Cereal Chemists, 1982).

Figure 7-14.—Moisture Migration Patterns in Rising Temperatures



SOURCE: G.H. Foster and J.L. Tuite, "Aeration and Stored Grain Management," in *Storage of Cereal Grains and Their Products* (St. Paul, MN: American Association of Cereal Chemists, 1982).

outside air is warmer than the grain, the area of condensation is several feet under the grain surface, but still in the center.

This moisture migration during storage means that grain assumed to be in a storable condition will not remain so over time. Cold weather migration primarily affects grain in land-based storage, causing deterioration as temperatures rise in the spring. Warm weather migration is particularly vexing for grain in transit both from cold to warm areas of the United States and from the United States through warm waters to foreign buyers. A barge or ocean vessel is basically a storage bin and will experience the same moisture migration phenomena as land-based storage facilities. Although aeration is the tool for managing moisture migration, grain in transit cannot be aerated, and ventilating the top of barges or ocean vessels does little to remove moisture or heat.

Aeration

Maintaining low temperatures and moisture levels in grain is the principal way to preserve grain quality and prevent damage from molds and insects. Aeration is a very effective tool for controlling moisture content and temperature. The rate of development for both molds and insects is greatly reduced as the temperature is lowered.

Aeration systems generally provide an airflow rate of 0.02 to 0.10 cubic feet per minute per bushel of grain. This is equivalent to 2 to 12 changes of air per hour. Aeration fans can be located at the base of a bin to create either a positive pressure pushing air up through the grain or a negative pressure by pulling air down through the bin. Some installations use fans mounted in the roof or bin top and some use fans, top and bottom, that pull and push the air.

Resistance to airflow increases with grain depth, so more power is required to aerate deep silo-type bins than shallow horizontal storage. Aerated bins and warehouses must have adequate ventilator area in the top to allow air to enter or exit when the fans are running.

The equipment and methods used to fill a storage bin affect the aeration system's performance. Dropping grain into the bin's center causes a cone to develop—with the lighter, less dense material concentrating in the center (spoutlines) while the heavier, denser material flows to the sides. This impedes airflow during aeration and molds can begin to grow almost immediately. In grains with relatively high amounts of fine material, such as corn, spoutlines are often removed from upright storage bins by drawing some of the grain out from the bottom, a practice called coring.

In large horizontal storages, loading from the center or from a loader that is gradually moved backward through the center of the building as the pile is formed causes similar problems. If grain is piled over each aeration duct on the floor by moving the loading device back and forth, airflow will be greatly increased. Airflow distribution is not as uniform as in upright bins, however. Some methods of filling piles also result in fine material concentrating in local areas. Piles, however, are difficult to aerate and their shape alone restricts uniform airflow.

Condensation in aeration ducts can be a problem when the fans are not running during warm weather and when the grain mass is cold. If outside air can enter the duct, moisture will condense there. Likewise, moisture from warm grain can condense on a cold aeration duct exposed to outside air. The accumulated moisture allows mold to grow, sometimes caking the grain around the perforated ducts. Air valves or tight-fitting covers should therefore be used to prevent air infiltration when the fans are not running.

Although aeration is primarily used for temperature control, grain moisture can be changed depending on the humidity, airflow rate, and length of aeration time. If wheat with 13 percent moisture is aerated with air at 40 percent relative humidity, there will be a gradual moisture loss from the grain. Humidities above 70 percent tend to add moisture to the grain. For this reason, coupled with the cost of operation, aeration systems are often run at the minimums considered necessary.

Many bins, especially on the farm, are equipped with aeration systems but are often not used effectively (27). Farm storage bins, especially smaller and older ones, often are not aerated. Small bins (holding less than 3,000 bushels) will cool or warm quickly enough with the changing season that moisture condensation may not be a serious problem. Farm bins that are aerated, on the other hand, are more likely to have systems improperly sized for the bin.

A majority of farm aeration systems are either not operated at all or not operated sufficiently (61). The most common problem is not running the fans long enough to bring the entire grain mass to a uniform temperature. If a cooling front is moved through only part of the grain, a moisture condensation problem is likely at the point where the warm and cold grain meet.

Temperature Monitoring

One way to monitor temperature is through the use of temperature cables. These can be hung from the roof or bin top and extend down through the grain mass. Each cable has a steel support cable and a number of thermocouple wires in a protective plastic shield. Cables can be placed in the bin before it is filled or can be probed into the grain, as is the case for horizontal storages and piles. As grain that is heating more than 1 or 2 feet from a thermocouple may not be detected until considerable damage is done in the hot spot, spacing and the extent to which detection is desired are critical.

Temperature increases that cannot be explained by changes in ambient conditions are a signal of possible mold or insect problems and should be investigated. Commercial facilities have relied on temperature monitoring systems for years, and many farmers also monitor grain temperatures.

Most temperature monitoring at commercial facilities is done on a fixed schedule either manually or by automatic recording equipment. A few facilities have installed programmable equipment that can be used in conjunction with aeration fan controllers. The system can be programmed to respond to higher temperatures by switching on an aeration fan. The cost of such systems has thus far limited their use to a few large companies.

Transfer Turning

Transfer turning is the process of physically moving grain from one storage bin to another. It is used primarily in upright storage facilities that have bins linked together by conveying equipment. The turning process mixes grain and contributes to a more uniform moisture and temperature. When hot spots are detected, the affected bin may be unloaded and transferred to another bin to break up the hot spots and allow the facility manager to identify and treat the cause. In facilities not equipped with aeration, turning has been the traditional means of grain cooling. It requires much more energy than aeration does, however, and can contribute to physical damage by breaking the kernel.

Turning grain cannot be performed in horizontal or pile storages because of the difficulty in unloading and moving the grain. To turn grain efficiently, a facility should have empty bins at its disposal that are connected by a conveying system. This is not the case on most farms. When bin space is limited, a bin can be unloaded and reloaded in one continuous operation.

Emerging Technologies

Little new technology is available in grain storage, but some technologies have been recently improved or applied. Programmable controllers for aeration systems are now available that monitor ambient temperature and humidity as well as grain temperature and that can be set up to run aeration fans. These will reduce management errors such as not moving a cooling front completely through the grain or aerating when weather conditions are unsuitable.

INSECT MANAGEMENT INTERVENTIONS

As indicated in the preceding section, insects create numerous economic and quality problems in stored grain. Losses due to insects worldwide range from 3 to 40 percent of the grain produced (44).

Preventing insect infestations should begin on the farm with an effort to clean grain and remove foreign material. (Cleaning technologies are discussed more fully later in this chapter.) A protective treatment, such as malathion, should be used if grain will be stored on farm. Beyond routine cleaning and spraying of empty storage facilities, few preventive treatments are applied to freshly harvested grain (7,61). These treatments are performed mostly on wheat, but sometimes on corn or soybeans. Also, protective treatments are used most frequently in the southernmost grain-producing States, where the climate is most favorable for insect activity.

As grain is marketed and moves from the farm through various facilities for export or domestic use, it is impractical to maintain the identity of a particular lot that has been treated. Thus, a treated lot may receive additional insecticides or fumigants as it moves through the marketing chain. This can result in adulteration of either the grain or the finished product with excessive pesticide residues.

In the absence of preventive treatment, infestations are controlled on a case-by-case basis as they occur. If grain is turned, a protective treatment may be applied. Exposed adult insects may be killed, but the immature ones inside the kernels will not be killed until they emerge as adults. Even when grain is fumigated, a 100-percent kill may not be achieved. The population may be reduced to an undetectable level and several generations may pass before infestation is detected. In either case, numerous immature and even pre-emerging adult insects remain inside the grain kernels. Many are not removed by the preconditioning processes used in the milling process, and insect fragments can be found in finished products.

With present technology, pesticides are the only available and entirely satisfactory method of ridding grain of live insects. The use of other control measures is severely limited by the inability to penetrate grain depths, available time for application and kill, quantity to be treated, and the product cost (including labor).

Pest control in grain storage facilities and transportation vehicles is therefore economically driven. If it costs money it will in all likelihood not be undertaken unless not doing so would prohibit grain sales. Of course, this is true not only for the use of pesticides, but also for aeration, turning, cleaning, or other measures to control damage and/or prevent quality losses. Although this approach is an option in a free market, it can result in situations where buildup reaches such proportions that preventive approaches such as aeration, turning, and the application of residual pesticides no longer work. Emergency or corrective actions, such as the use of a fumigant, are then needed.

Current Pesticides

The pesticides used to control live insects can be divided into two broad categories: insecticides and fumigants. Insecticides are applied to facilities or directly to grain. The term "grain protectant" refers to the application of an insecticide to grain as it is conveyed into storage. The application is expected to provide a residue that will protect the grain from insects during storage. When properly applied, grain protectants should prevent or minimize additional damage caused by existing infestation and protect clean, uninfested grain from becoming infested. Insecticides labeled as grain protectants can also be applied to empty storage facilities, although these must be cleaned beforehand if the full value of the treatment is to be realized.

The term "fumigation" is often used incorrectly today. Many people believe that any application of fine insecticide particles into an enclosure or building as an aerosol, fog, mist, or smoke is to fumigate. But fumigation is a separate technology from other chemical control methods:

> . . . a fumigant is a chemical which, at a required temperature and pressure, can exist in the gaseous state in sufficient concentrations to be lethal to a given pest organism (9).

As this definition implies, fumigants act as a gas in the strictest sense of the word; they can penetrate into the material being treated and can then be removed by aeration. Fumigation, therefore, is a highly specialized art involving the application of some of the most toxic and unique pesticides. It requires professional personnel who are well trained and experienced regarding both the fumigant and the target organism.

Insect infestations usually involve a complex of insect species, and each species and life stage differs in its susceptibility to an insecticide or fumigant (22,26). The dosage must therefore be directed against the least susceptible life stage.

Grain Protectants

For many years, synergized pyrethrins were the only insecticides approved for use as a grain protectant, although none are approved for use on soybeans. Consequently, they have a long history of safe usage. Pyrethrins are both toxic and repellant to many species and have a rapid "knock down" effect. This does not mean the insects are dead; in fact, they may recover with no detrimental effect (42). Even though pyrethrins have been used for many years, insects have developed little resistance to them.

Several factors have limited the use of pyrethrins during the past 15 to 20 years. Pyrethrin extracts must be imported and, as such, the supply is not as reliable as desired. With the approval of malathion as a grain protectant, pyrethrins were no longer economically competitive. Also pyrethrins lacked the biological efficacy desired as a grain protectant (less than 100 percent kill of some species and life stages) that appeared more promising with malathion.

Malathion has been the insecticide of choice for more than 20 years, although it too has never been approved for use on soybeans. Convincing evidence of insect resistance to malathion was first reported in the mid-1960s, and during the last 15 years alarmingly high levels of resistance have been reported. Because there is no practical and economical alternative, malathion continues to be used even though its value as a grain protectant is doubtful in many cases (23).

Pirimiphos-methyl has been recently introduced. The commercial name for this product is Actellic. It controls a wide range of insect species, including those resistant to malathion. Pirimiphos-methyl was approved for use on export corn and wheat (but not on soybeans) in 1986. In 1987, it was approved for domestic corn use. It is approved for use on stored grain in 14 other countries (36).

Chlorpyrifos-methyl has also recently been introduced. The commercial name for this insecticide is Reldan 4E. It controls a wide range of insect species including those resistant to malathion. In 1986, it was approved for use on wheat but not on corn or soybeans. A dust formulation has been approved for use as a protectant for wheat and corn but not soybeans.

Bacillus thuringiensis (BT), a bacterium, is the only insect pathogen used as a grain protectant. To be effective, the spores must be ingested by the insect; however, only moth species of grain pests are controlled by BT. BT provides little or no control of grain beetles or weevils.

Inert dusts, such as silica aerosols, magnesium oxide, aluminum oxide, diatomaceous earth, and clays, have varying degrees of potential as grain protectants. In general they are slow-acting and kill insects mainly by an abrasive action that results in desiccation of the insect. They do not perform well in moist grain or in high temperatures. The disadvantages to using inert dusts may outweigh their value. These include environmental contamination, damage to machinery, increased fire risk, lung damage to workers, and reduced grade and/or test weight of grain. As such, relatively little use has been made of inert dusts in the United States (26).

Fumigants

A structure must be gastight for fumigation to be successful. The fumigant gas concentration must be maintained long enough to kill the least susceptible life stage of the insects involved. Most fumigation failures can be traced to inadequate gastightness of a storage facility; higher dosages will not compensate for such deficiencies (66).

An ideal fumigant should be:

1. highly toxic to all life stages of the target insect;
2. relatively nontoxic to humans and animals;
3. highly volatile, with good penetrating ability;
4. noncorrosive to metals;
5. nonflammable or explosive under practical conditions of usage;
6. nonreactive with the commodity (does not produce an adverse flavor, aroma, or residue);
7. nonharmful to seed germination;
8. economical, readily available, and simple to use;
9. fast acting, able to be aerated quickly, and nonharmful to the environment; and
10. easily detectable, with adequate warning properties.

Unfortunately, there is no ideal fumigant. However, the grain fumigants available possess some of these characteristics. Therefore, it is very important that fumigators be well informed on the performance characteristics of each fumigant so that a fumigation can be performed in a safe and effective manner. Two compounds—methyl bromide and hydrogen phosphide—are presently available as grain fumigants. Of these hydrogen phosphide is the fumigant of choice.

Methyl bromide is highly toxic to all life stages of grain insects and humans. Because it is essentially odorless, extreme care is necessary to avoid exposure. As methyl bromide is a liquid under pressure, it is highly volatile, but to achieve good grain penetration, forced recirculation is required. Methyl bromide gas is noncorrosive to metal, but the liquid phase reacts with aluminum in the absence of oxygen to form a compound that ignites spontaneously in the presence of oxygen. It is, however, neither flammable nor explosive under practical conditions of fumigation.

This fumigant reacts with most food commodities and grains to produce inorganic bromide residues that are permanent and accumulate with each additional fumigation. It also reacts with a host of other nonfood items, especially those that contain sulfur compounds. The degree of reaction is relative to the dosage applied, product temperature, duration of the fumigation period, and the number of times it is applied. When the inorganic bromide tolerance is exceeded, adverse flavor or aroma (or both) of the product may occur.

Methyl bromide is economically competitive with other fumigants and is readily available to authorized personnel. Using it requires special equipment both for application and safety. Because it is a liquid under pressure, knowledge and experience in using the equipment is essential. The need for recirculation substantially limits its use. Recirculation equipment is expensive and can only practically be used in facilities that are sufficiently gastight to prevent gas losses caused by the positive pressure of the system.

Fumigations can be completed within 16 to 24 hours, as methyl bromide is considered to be as fast acting as most fumigants. The recirculation system used during application can be used as an aid in aeration. Most of the unreacted methyl bromide can be aerated in 3 to 4 hours; however, atmospheric aeration should continue for 48 hours or more before moving the grain. As methyl bromide is practically odorless at low levels that are dangerous to humans, it lacks adequate warning properties.

Hydrogen phosphide will probably continue to be the fumigant of choice within the foreseeable future. It falls short of the ideal, but has many usable qualities not available in any other fumigant. It is highly toxic to all life stages and is very toxic to humans. Hydrogen phosphide is highly volatile with excellent penetrating quality. It is formulated as a solid either as aluminum or magnesium phosphide. Gas is released when the formulation is exposed to the atmospheric moisture. However, it is corrosive to certain metals such as copper gold, and silver.

This fumigant can be highly flammable or even explosive under conditions of misuse, such as application resulting in extremely high concentrations of gas. It does not react with grain to cause either adverse flavor or aroma nor does it cause excessive residues. Hydrogen phosphide is economical, readily available, and the simplest fumigant to apply. A formulation can simply be scattered randomly, placed systematically on the grain surface, or submerged into the grain. Many methods have been developed to increase gas distribution in the grain mass. Hydrogen phosphide is not a fast-acting fumigant compared with methyl bromide, and it can take 3 to 5 days or longer depending on the temperature. Even longer periods are required when large masses are to be fumigated.

With cross-ventilation, hydrogen phosphide is removed from the free space in storage facilities within minutes. Low gas levels may continue to evolve from the grain, but with continued cross-ventilation, people can enter the facility and even work with the grain. Hydrogen phosphide is easily detected by use of detector tubes and contains an odor so it can be detected at very low levels. Although the odor can be a useful warning sign, it may not persist throughout the fumigation to therefore provide adequate warning during aeration.

Among the chemicals used as insecticides, fumigants are the finest tools available. Fumigation, however, is the last line of defense when all other insect control methods fail. Special care needs to be exercised to avoid any exceeding tolerances that may lead to cancellation by regulatory authorities or the loss of effectiveness due to development of insect resistance. Although the technology is available to accomplish 100 percent kills of the target insect, the diversity of storage facilities and conditions under which fumigation is performed means a 100 percent kill is seldom achieved.

Most fumigations are of a commercial or economic control type. This is accepted because most storage facilities are not sufficiently gastight to retain the fumigant, and the cost of securing gastightness may be prohibitive. This type of fumigation is often accepted where very large grain masses are involved or when time is limited, such as in large elevators and export grain in shipholds Although some of these facilities may be sufficiently gastight, the technology for achieving gas distribution throughout the grain mass has not been adequately researched and developed.

If there are enough insects to require fumigation, there are greater numbers of immature insects living inside individual grain kernels. Commercial or economic control fumigations often do not kill these immature insects. Though the grain may pass visual inspection for live adult insects, many of the immature insects develop and emerge as adults within the next 2 to 4 weeks and the grain is reinfested.

Two important problems arise from this type of fumigation. First, shipments certified as not being infested may arrive at their destination infested. Second, insects not killed by fumigation are exposed to sublethal dosages, which is the basis for developing resistance. Insect resistance to any of the fumigants means a major loss in this last line of defense.

Conditions Affecting Insect Management

The application and effectiveness of residual insecticides and fumigants may be seriously limited by the amount of time available, the space or volume of grain to be treated, the economics or dollar value saved or gained by their use, or legal restrictions on the use of various pesticides by local, State, or Federal authorities. The effectiveness of residual insecticides depends on the grain and storage facility being properly treated: The insect must come in contact with the residual before the pest will be killed. Similarly with fumigants, if there is not sufficient time for the gas to reach all parts of the grain mass in the required quantity and for the required duration, the pest will survive.

Types of Storage

The types and quality of grain storage facilities vary greatly, as noted earlier in this chapter. Farm storages have generally been suitable for fumigating with liquid fumigants (e.g., carbon tetrachloride, ethylene dibromide, ethylene dichloride, carbon disulfide, and chloropricrin) that were poured, sprinkled, or injected into the grain. These liquid fumigants are no longer available, and it is questionable whether some of these facilities can be sealed adequately and economically to retain fumigant gas such as hydrogen phosphide. In some cases, farmers may be advised to increase fumigant dosage to compensate for gas leakage. This will result in failures and can lead to insect resistance and ultimately the loss of the fumigant from the market.

For several reasons—such as remoteness of farm storage facilities, small amounts of grain to be treated, inadequate storage structures, and lack of information—much on-farm grain may never receive properly applied insect controls. When this infested grain is marketed, it comingles with noninfested grain and inflates the problem (7).

Although many high-quality on-farm storage facilities boast good pest management practices, the well-constructed facilities that utilize pest management technologies are generally found in commercial handling facilities that use upright silos (or bins) or horizontal (flat) storage. They are usually equipped with some type of forced aeration for cooling and drying. These systems are not designed for recirculation, which is required for fumigation with methyl bromide. Most horizontal or flat facilities are not adequately gastight for fumigation with either of the available compounds. Hydrogen phosphide can, however, be used when facilities are adequately gastight.

Most upright storage structures are gastight or can be made adequately gastight with a minimum of sealing. The ideal time to fumigate with hydrogen phosphide or apply an insecticidal protectant is when the grain is conveyed into storage. However, it is impractical to apply a fumigant at this time because the flow or supply of grain is irregular, and much of the harvest must be completed before the storage is filled. Thus, a great deal of the fumigant gas is lost as grain is added. The next best treatment opportunity is when turning grain from one full tank or silo to an empty one. This is not always done because empty storage space may not be available and it is expensive to turn grain. Sometimes grain is fumigated by probing or submerging fumigants into the grain surface. Most of these fumigations are only partially effective because sufficient time is not allocated to effect gas distribution.

Port Facilities

All port facilities have upright storage structures, although these are best described as handling, not storage, facilities. Any type of insect control remedy can cause expensive delays in loading. Because of the different types and grades of grain handled, even the largest port facility can seldom store enough grain for one shipment. Instead, enough grain is held to begin loading a ship, then a constant flow of grain from railcars and barges is unloaded into the facility and transferred directly onto the ship. Incoming grain that is infested can be set aside and fumigated before unloading, but grain found to be infested after loading on the ship is usually fumigated with hydrogen phosphide while in transit.

Transportation Modes

The time grain normally spends in various transportation modes—combines, trucks, railcars, and barges—is minimal. Yet these can be important sources of infestation. Prolonged storage, especially in ocean vessels, is a unique situation that should be treated as storage rather than transportation.

To be effective, a fumigant gas must be distributed throughout the grain mass and held for the duration required to kill the insects involved. Few transportation modes are adequately constructed to retain fumigant gases. Those that may be sealed or made gastight include covered hopper railcars and hopper-type trucks. Other types of railcars, trucks, and even barges cannot be made gastight either at all or economically. Ocean vessels, on the other hand, have proved to be effective locales for fumigating grain in transit.

Outside Factors

Physical.—Many physical factors affect the performance of chemical interventions. Among these are temperature, moisture, and humidity. Temperature probably has the greatest impact. Usually within well-defined limits, an increase or decrease in temperature means a similar increase or decrease in the insecticide's performance. Temperature most dramatically affects the performance of fumigants, especially methyl bromide. High-moisture grain increases absorption of fumigants such as methyl bromide, requires higher dosages, and accelerates the breakdown of protective treatments such as malathion. The influence of humidity is varied, with minimal effect on the performance of most pesticides. However, hydrogen phosphide formulations require at least 25 percent relative humidity to cause the chemical reaction that releases the gas.

Foreign material and dockage covers a wide variety of items, but grain dust and other fine materials have the greatest effect on the performance of insect control interventions. When a protective treatment is applied, grain dust may absorb much of the insecticide, reducing its effectiveness. Likewise, concentrations of dust and fine material may require increased dosages of a fumigant to penetrate the grain mass. Dust also inhibits penetration of fumigant gases and causes the gas to channel so that penetration is slow or nonexistent in certain parts of the grain mass.

Human.—The competence of applicators is a major factor in the performance of any pest management intervention. An incompetent or inadequately trained applicator may apply too little or too much pesticide. The grain is either not protected or it may be contaminated with residues from high dosages. Inadequate training and experience are most likely on the farm, where pesticides are often applied by farmers themselves.

Biological.—Several biological factors must be taken into account for successful insect control. Some of the most important factors include the species and life stage of the insects involved, insect resistance to the insecticide, kind and condition of the grain to be treated, and the presence of beneficial organisms such as parasites and predators.

Infestation usually involves several insect species, and susceptibility to insecticides varies among species, life stages, and even the age of the insects within a species. Therefore, the insecticide or fumigant must be directed toward the least susceptible species and life stage. Several insect species are highly resistant to malathion and/or moderately resistant to synergized pyrethrins (69), and a few species have developed low levels of resistance to hydrogen phosphide (13).

Financial.—The cost involved should not be a deterrent to the timely and proper application of insect control. Studies indicate that materials cost less than 1 cent per bushel and that complete programs involving treating empty bins or warehouses average 2 cents per bushel (67). Other studies indicate that farmers do little to maintain quality during storage on the farm even though grain is discounted for live insects (7).

Discounts assessed for live insects are quite variable. Discounts in Minnesota are reported as high as 17 cents per bushel for corn to 33 cents per bushel for wheat (27). A survey of commercial handling facilities across the Midwestern States reported discounts ranged from 1 to 20 cents per bushel (62). Obviously, the incentives to initiate and maintain insect control measures and deliver insect-free grain are either lacking or in question.

New and Emerging Technologies

The greatest potential for new residual-type pesticides may be in expanding the approved usage of the relatively new insecticides pirimiphos-methyl and chlorpyrifos-methyl. Both compounds appear promising as replacements for malathion. Both are effective against malathion-resistant insects, but are less than totally effective against the lesser grain borer, a major pest to stored grain. In Australia, mixtures of bioresemthrin, a synthetic pyrethroid, with chlorpyrifos-methyl have been shown to be effective. The use of insecticide mixtures has not received much attention in the United States because regulation requires safety data on all components as well as the mixture.

Several new approaches to insect control or prevention have been researched and brought to a usable point, but they have received little or no acceptance within the grain marketing system because of costs or predetermined performance limitations.

Modified atmosphere is a relatively new technology. Its basic performance needs are similar to those of a fumigant in that the facility must be gastight to retain a modified atmosphere of either nitrogen, carbon dioxide, or no oxygen for several days. The use of carbon dioxide appears to have the greatest potential.

Regardless of whether nitrogen or carbon dioxide is applied or an exothermic burner and condenser is used to create a low oxygen atmosphere, the logistics of providing large quantities of these substances or the initial cost and maintenance of the burner system will hinder implementation.

Hermetic storage involves total sealing, after a facility is completely filled, to exclude oxygen. Then, during long-term storage, the natural respiration of the grain and insects will deplete the oxygen and create an atmosphere lethal to the insects.

Much research has been completed on using irradiation to kill or sterilize insects and to disinfect grain. Recent studies indicate that the electron acceleration method of irradiation is the most practical and may be the most economical. Adoption of irradiation has been limited because of the high initial cost of installation. Installing an accelerator capable of treating 1,000 tons of grain per hour would cost some $4 million (10). By operating the unit two shifts per day, 6 days a week, the maximum annual throughput would be 5 million tons. With this throughput and taking into account all foreseeable operating costs, treatment would cost about 23 cents per ton.

At a temperature of 16 °C or lower, insect activity ceases. Little or no feeding or reproduction occurs, but many insects will survive long periods at these temperatures. At temperatures near freezing, it requires 10 days or more to actually kill some species. Obviously the technology is available to modify temperatures to maintain quality of certain high-value agricultural products. However, it would be economically impractical to freeze large grain masses by mechanical refrigeration. Where climate provides naturally cold temperatures, aeration systems in storage facilities are used to reduce grain temperature to achieve insect control.

High temperatures can also kill insects. Studies using high temperatures concluded that microwave and infrared radiation can heat grain in thin layers, such as found on conveyor belts, to disinfest it (39).

TRANSPORTATION

The U.S. grain transportation and distribution system is probably the most efficient one in the world (8). Much of this efficiency was achieved during the 1970s when demand for export grain placed enormous stress on the system. Improvements made then resulted in high-speed, low-cost transportation and grain distribution. It is estimated that the United States is now capable of exporting over 8 billion bushels of grain per year, whereas in the mid to late 1970s the system was under great stress to export 3.5 billion to 5.0 billion bushels.

Current Modes of Transport

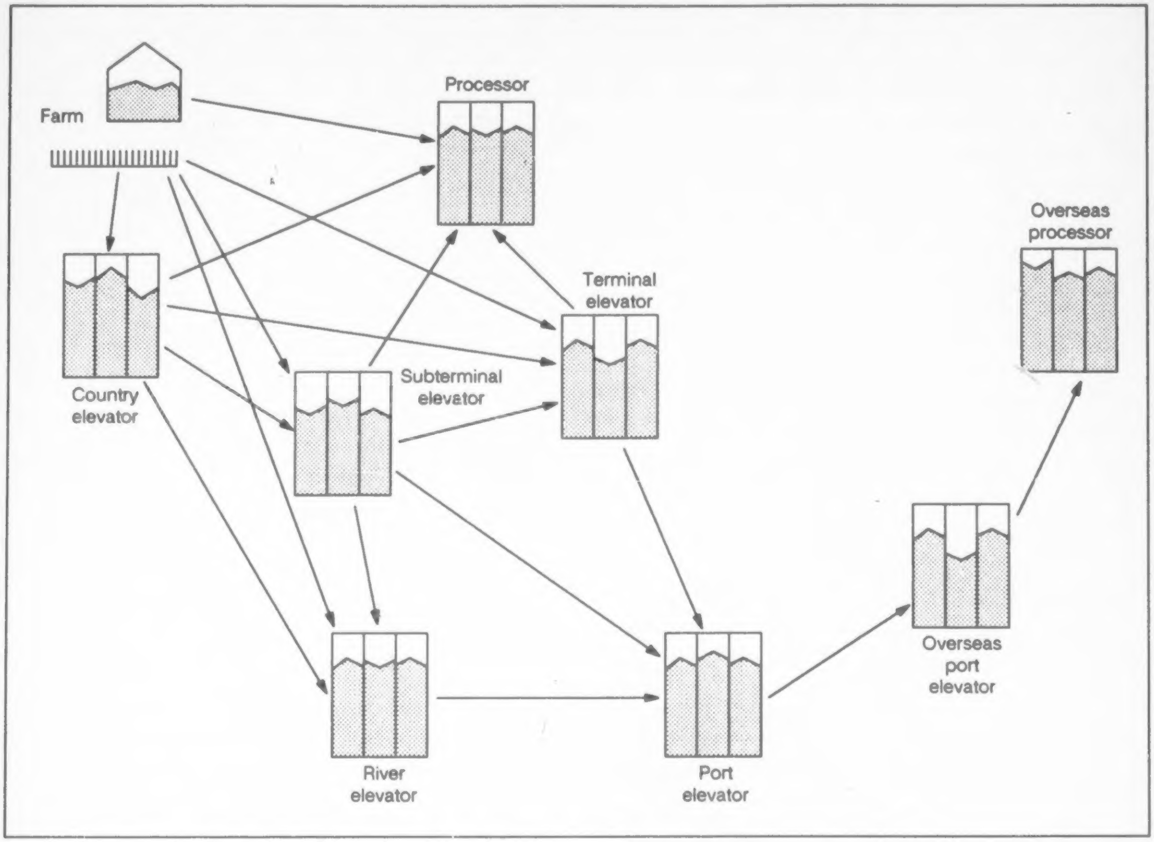
Grain may be moved from farms to country elevators or to inland terminal elevators, or directly to domestic end users (figure 7-15). Domestic users may obtain grain directly from farms or from country, subterminal, or terminal elevators by truck or train. Grain for export can be shipped from these elevators directly by rail, by truck to barge, or by rail to barge to export elevators in major U.S. ports for loading onto ocean-going vessels. Some farmers close to export elevators bring grain directly to these facilities by truck. Grain is also shipped by rail from subterminal or inland terminal elevators to Mexico, and small amounts of wheat and corn move directly into Canada by truck. Thus, the major carriers of grain are trucks, trains, barges, and ocean vessels.

Accurate measurement of the share of grain hauled by each mode of transportation is difficult since no agency collects data on grain shipments by truck. Also, more than one transportation mode may be used to move grain from a country elevator to the final user. Information on the total quantities of grain moved by rail and barge is available (table 7-6). The share of transportation by train ranged from a high of 80 percent in 1974 to a low of 66 percent in 1982. Barge shares tend to rise and fall as exports increase or decrease, primarily because most grain moving by barge is destined for export. The share of grain moving to export by rail declined from 62 percent in 1974-75 to 38 percent in 1983-84, while the share by barge increased from 37 to 60 percent (3).

By Rail

Trains have been the major carrier since the late 1830s, and single boxcar shipments remained the dominant grain transportation technology until the late 1960s. The use of boxcars, however, resulted in grain damage. The grain was loaded through a center door using flexible pipes that direct the grain flow into either end of the boxcar. Grain throwers were also used to assist in this process. Once loaded, the grain was leveled by hand. Since boxcars had no unloading devices, unloading involved an electric shovel that was dragged or pulled by

Figure 7-15.—General Flow of Grain From the Farm Through the System



SOURCE: U.S. Department of Agriculture, Office of Transportation, "The Physical Distribution System for Grain," Agriculture Information Bulletin No. 457, Washington, DC, October 1983.

Table 7-6.—Grain Hauled by Railroads and Barges, 1974-1985

	Billions of bushels moved by		Percent moved by	
Year	Rail	Barge	Rail	Barge
1974	4.21	1.03	80.3	19.7
1975	4.06	1.20	77.3	22.7
1976	4.10	1.61	71.8	28.2
1977	3.91	1.52	72.0	28.0
1978	4.12	1.63	71.7	28.3
1979	4.41	1.62	73.1	26.9
1980	5.00	1.91	72.4	27.6
1981	4.38	1.99	68.8	31.2
1982	4.22	2.18	66.0	34.0
1983	4.72	2.11	69.1	30.9
1984	4.81	1.97	70.9	29.1
1985	3.99	1.67	70.5	29.5

SOURCE: Association of American Railroads, *The Grain Book 1986* (Washington, DC: 1987).

a cable to the center door, using an electric motor. Unloading devices were designed to lift and tip the entire car in either direction so the grain would flow out the center doors. The whole process of transporting by boxcar was labor-intensive and damaging to the grain.

Boxcars were also a ready source of insect infestation since they have an inside wood wall liner. Frequently these were damaged, and bulk material, including grain from previous shipments, became lodged behind the liners. This material was for all practical purposes impossible to remove and, therefore, became infested and contaminated the next cargo.

The advent of the covered hopper car in the mid-1960s greatly reduced the loading and unloading stress on grain quality. Covered hopper cars have full-length top hatchways for relatively easy loading that does not require throwing or leveling. Each car consists of three to four smooth, hopper bottom compartments. Since grain is unloaded by gravity flow, each compartment is essentially self-cleaning, reducing the risk of insect infestation in the next shipment. The covered hopper car is tight and essentially leak-proof, making it easier to fumigate than boxcars. Moreover, loading and unloading is less labor-intensive and damaging to grain. By 1985, 99.6 percent of all grain transported by rail moved in covered hopper cars.

Until the mid-1960s, almost all grain transported by rail moved under single-car transit rates. This means that grain was shipped to a transit location (an elevator), unloaded for storage, and later reloaded and shipped to its final destination. The transit rate was usually lower than the inbound rate to a location plus the outbound rate to the final destination. In the mid-1960s, however, rail companies began offering low-cost, multiple-car and unit-train rates from country elevators direct to final destination, thus eliminating the stopover at transit locations.

Unit trains are a group of railcars shipped from one origin to one destination on one bill of lading and consist of 50 or more railcars. The unit-train concept eliminated the need to stop at numerous elevators to pick up cars for switching into a train. Turnaround time from the country elevator was much faster for unit trains than for single-car shipments. Thus, unit trains lowered costs of switching, fuel, and crews, and enabled companies to haul more grain with existing fleets. A portion of these savings were passed onto shippers in the form of lower rates, which enabled rail companies to be more competitive.

By the mid-1970s, multiple-car and unit-train shipments became the standard method for transporting corn and soybeans by rail. This shift to large direct rail shipments reduced not only grain transportation costs but also grain damage by eliminating unloading and reloading at transit elevators.

While the single-car transit system has been virtually nonexistent in the corn and soybean market since the mid-1970s, it continues to perform a major function in wheat distribution, particularly in areas producing Hard Red Winter wheat. More than half the wheat transported by rail from Kansas, Oklahoma, and Texas moves under transit rates. In part, this is because a large percentage of the grain storage capacity in these areas is located at inland terminals. In contrast most storage capacity in the Corn Belt and the wheat-producing areas in the Northern Plains States is located at country elevators, and multiple-car and unit-train shipments are now standard. In addition, aggregating large quantities of wheat at inland terminals permits blending of Hard Red Winter wheat to meet export standards. Only a small number of country elevators in these areas are capable of blending wheat to meet export specifications.

By Barge

Most grain moving by barge originates on the Mississippi River system, which includes the Illinois and Ohio rivers. These rivers became navigable when a system of locks and dams made the entire river system navigable at 9-foot drafts in the 1930s. The major export locations served by barges are the Mississippi River elevators in New Orleans and the Pacific Northwest ports that are served by the Columbia and Snake rivers.

All grain moving by barge must be transported by truck or rail to barge-loading facilities, unloaded, and then reloaded into the barge. Barge tows, consisting of 12 to 30 barges pushed by a towboat, make the trip from barge loading facilities on the upper Mississippi to export elevators in New Orleans in 15 to 25 days.

Barges are not self-unloading, so unloading causes more grain damage than unloading hopper-type railcars. Typically barges are unloaded by lowering into the barge a marine leg or vertical belt with large buckets attached to scoop up the grain. When a barge is partially unloaded, a small crawler tractor with a front-end blade is lowered into the barge to push the remaining grain to the marine leg to complete unloading.

The major advantages of barges over railcars are the large carrying capacity of barge tows and the relatively low rates charged to transport grain to deep water ports in New Orleans. Table 7-7 shows the range of rail and rail-to-barge rates for grain shipped from central Iowa to New Orleans. Rail rates decline as the size of the shipment increases in both situations, but are still higher than for barge shipments.

Barge rates respond to supply and demand. During the 1970s, barge rates fluctuated between 100 and 200 percent of the Merchants Exchange of St. Louis trading benchmarks. Even with barge rates at 200 percent of tariff, however, the combined rail-to-barge rates are sharply lower than rates on rail direct to New Orleans. The rail rate advantage only increases with origins located closer to New Orleans.

Other advantages of barge movements are that they can be used as an extension to the export elevator for storage and that barges can be marshalled and unloaded in the New Orleans area. Many export elevators in New Orleans are high-speed transfer facilities with limited storage that are equipped to unload barges rapidly, usually one per hour. These elevators would be hard-pressed to unload the equivalent amount of grain from railcars in an hour and still maintain low-cost, high put through rates. Barges with specific qualities and quantities being stored on the river are controlled by the grain companies in the New Orleans area. These can be collected and moved to the elevator based on quality demands of a particular shipment at specific times desired. Unloading railcars means extra work in dealing with individual smaller units and storing specific quantities in the facility. Also, switching railcars into the facility and removing empty cars is subject to the availability of train crews. This places the facility at the mercy of the rail companies regarding delivery schedules when an entire export shipment is not in the facility.

Table 7-7.—Comparison of Rail and Rail-Barge Rates From Jefferson, Iowa, to New Orleans in Dollars Per Ton

Mode	Size of shipment	Rail direct to New Orleans	Rail to Clinton, IA, barge to New Orleans
Rail	25-car	$25.40	$ 7.20
	50-car	23.60	6.60
	75-car	21.40	6.00
Barge at 100% of tariff			5.32
Barge at 200% of tariff			10.64

SOURCE: C.P. Baumel, "Alternative Grain Transportation and Distribution Technologies and Their Impacts on Grain Quality," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

By Ocean Vessel

In the 1960s, the Public Law 480 program dominated grain exports. A substantial portion of these exports were shipped in small (10,000 to 15,000 ton) vessels. Many of these were multipurpose vessels ('tween deckers) with several decks and small holds. Loading often caused grain damage. To provide cargo and vessel stability and to obtain full utilization of capacity, these vessels had to be trimmed, which involved throwing the grain under ledges and into corners of small holds, causing more grain damage. These vessels were difficult to unload and fumigate for the same reasons.

During the 1970s world prosperity increased cash export sales substantially. Importers and exporters shifted a high percentage of their shipments to larger vessels (50,000 tons or more) to gain lower per-ton shipping costs. These vessels are relatively easy to load and unload because of their large open holds with rolltop hatches and smooth sides, and thus create less grain damage than the "tween deckers."

Grain can also be transported in tankers that are used primarily to ship oil. Loading tankers can damage grain, especially corn, because it must be loaded through a small opening, just big enough for a person to enter, in the middle of each hold. In each opening there is a permanently affixed ladder. As grain is loaded, it bounces off the ladder, causing increased breakage. Also, holds must be filled through very small openings at the corners to increase the hold's capacity. Based on the location of these openings, grain may have to be thrown and diverted into the opening. Unloading tankers is more difficult and causes additional grain damage because pneumatic unloaders are required.

Quality Problems That Arise During Transport

The grain transportation and distribution system aims to move grain from the farmer to its final destination at minimum cost, subject to maintaining a specified level of grain quality. As figure 7-15 indicated, a large number of routes are available. Assuming a minimum of two handlings (one in and one out) at each location, grain might be handled six to eight times when moving through this system. This figure does not include the number of times grain is handled on the farm or within facilities. Thus, the relationship between the transportation and distribution systems affects grain quality. Changes in one system will require changes in the other.

The grain distribution system, as currently organized, has large investments in duplicate and out-of-location facilities, which tends to increase the number of handlings. The abandonment of a large number of branch rail lines during the 1970s left many country elevators without rail service. Most of these facilities, however, are still in operation. A substantial portion of grain received at these locations must be trucked to another facility that unloads, stores, and reloads the grain into railcars. At least two handlings could be avoided if farmers delivered grain directly to facilities with rail service. In effect, the facilities on abandoned rail lines recreate the transit system for corn and soybeans that caused additional breakage due to increased handlings. (This is not as important for wheat, which is less affected by extra handlings.)

Other than increased breakage during loading and unloading, grain quality deteriorates in shipment in much the same manner as it deteriorates during storage. The negative impacts on grain quality presented in the storage section of this chapter regarding moisture uniformity and migration, temperature and humidity, insect invasion, and mold development also apply during shipment. This is because grain is in fact being stored while in transit.

Several factors peculiar to grain transportation must be noted, however. The areas discussed in the storage section as they pertain to solutions or preventive measures are not applicable to grain during shipment. For example, no mode of transportation is equipped with aeration, nor can grain temperatures and corrective actions be taken during shipment. Therefore, moisture uniformity is critical to maintaining quality. Moisture migration can be more dramatic during shipment since grain can undergo several outside air temperature and humidity changes. This is especially true when grain is loaded in a cold climate and moved through warm water rather quickly to a warm, humid climate.

Barge shipments appear to be more susceptible than railcars to these influences, since more time is spent in transit. One explanation is that railcars are more uniformly loaded than barges in terms of moisture, as barge-loading facilities have fewer bins for segregating different moisture levels. Also, barges are primarily used to transport corn and soybeans, with moisture and damage at higher levels than in wheat. Once grain is loaded into the mode of transportation that will carry it to its destination, maintaining grain quality is out of human control.

Grain travels up to 2,000 to 3,000 miles from the major grain-producing regions in the United States to ports. In the case of barge shipments, up to 3 weeks might be spent in less-than-optimum storage conditions. Spoilage in barge shipments to New Orleans have been found due to high moisture levels in portions of the barges. This happened in less than 3 weeks. Vessels used to transport grain to foreign buyers can take up to 50 days, not including port delays for unloading. This time increases the potential for grain spoilage and has been the focus of several studies on grain quality and the basis for many foreign complaints.

As discussed previously, as bulk grain is loaded, fine materials tend to accumulate in the center while the larger material tends to roll to the sides. The impact that concentrations of fine materials (spoutlines) have on grain quality can be minimized to some degree by moving the loading spout around so those materials do not concentrate in one spot. This cannot be done in tankers. But no degree of spout movement can completely eliminate the segregation of material in the hold of a vessel.

This creates some unusual problems beyond the effect fine materials have on quality. As vessels have gotten larger (for the reasons previously discussed), foreign buyers are receiving quantities that must be divided for distribution to the ultimate users. Many times the entire cargo is not reblended before being divided and distributed. This results in some users receiving higher quality (as defined by the average amount of fine material reported for the entire shipment) and some receiving poorer quality, even though the entire cargo was within specification.

Transport Techniques That Protect Grain Quality

Identity Preservation Within Ship Holds

One of the problems associated with large bulk shipments is the nonuniform nature in a ship hold of the grain that will ultimately be distributed to several users. One way to overcome this problem is to place a layer of burlap or plastic cloth and plywood between individual portions. Some countries specify that individual portions destined for specific users be separated in this manner.

Direct Transfer

One method for reducing the number of grain handlings is to transfer grain directly from one mode of transportation to another without unloading it into an elevator. For transfer from a railcar or truck to a barge, direct transfer could involve unloading the railcar or truck into a pit and transferring the grain by belt directly into a barge, thus eliminating the elevator handling. This method is currently being used in some locations.

Direct transfer from a barge to an ocean vessel can be accomplished with conventional unloading methods, marine legs, and movement by belt to the ocean vessel. A second method involves floating rigs. Currently, nine floating rigs in the New Orleans area perform this service. The cost, however, of direct transfer using floating rigs is higher than moving grain through export elevators.

Bagging

Export bagging facilities are currently in place at export elevators in Corpus Christi and Houston, TX, as well as in Pascagoula, MS. The bagging operation consists of placing grain into bags, sewing the bag shut, placing it on a pallet, and transferring the full pallet to a warehouse on the dock for loading to a vessel.

Most of the export bagging is currently being performed for Public Law 480 shipments of 1,000 to 4,000 tons per order. The cost is substantially higher: Bagging, including moving full pallets to a warehouse and then loading them, costs about $27.30 per metric ton compared with less than $1.00 for loading bulk grain (8). Bagging grain at country or inland elevators and shipping the bags to a port for loading would decrease the number of handlings.

Containers

Since the mid-1970s, most of the manufactured U.S. imports have been shipped in 20- and 40-foot containers. A large share of these return empty to Japan, South Korea, and Taiwan. Special high-quality grains such as seeds and soybeans for human consumption have been exported in these containers. However, little or no commercial-grade grains have been shipped in containers.

The cost of shipping containerized grain is significantly higher than any of the current bulk shipping technologies. One recent attempt to ship corn from Iowa in containers cost twice as much as the least-cost bulk handling rate. Grain loaded into containers at interior locations could be shipped overseas, thus reducing a significant number of handlings (8).

Identity-Preserved Shipments

The basic concept behind identity preservation is that individual grain shipments should not be comingled with others. Thus, the grain shipped from a specific location in the United States is the exact grain that the final user receives. Any of the previously mentioned modifications can be used for identity-preserved shipments. The associated costs are therefore related to the type of transportation mode selected. Much discussion has taken place on the merits of this concept, and several shipments have originated from interior locations for delivery to importing countries with their identities preserved.

Emerging Technologies

Only two new transportation technologies could help preserve grain quality: capsule pipelines and long-distance belts. The pipeline technology would move grain in capsules propelled by air pressure. Long-distance belts would carry the grain gently from one point to another.

Recent studies on the economic feasibility of capsule pipelines indicate that distance and quantity carried are the major determinants of the economic feasibility. The pipelines are cheaper than unit trains on shipments less than 300 miles and quantities in the range of 70 million to 80 million tons per year (8). The short distances mean that shipments would be limited to river terminals for loading onto barges for shipment to a port.

Large volume requirements are unlikely to be available to any inland shipping elevator unless the grain is trucked or railed to the pipeline loading elevator. This would raise costs and number of handlings. Once grain is loaded into a truck or railcar, usually the least cost method of transportation is to haul it directly to its destination.

The final remaining possibility for pipelines or belts is to transfer grain very short distances from large elevators to nearby export elevators or from export elevators to ocean vessels unable to reach the elevator because of shallow water. The widespread distribution of grain supplies in the United States effectively rules out the use of these technologies for moving grain from country elevators.

CLEANING AND BLENDING TECHNOLOGIES

Cleaning and blending are operations at the heart of many grain quality controversies. The purpose of cleaning is to remove material other than grain, shriveled kernels, and broken pieces of kernels. Blending is the mixing of two or more grain lots to establish a quality different from either lot. Blending is performed by exporters, individual elevator managers, and producers to assure uniformity and increase profits (33). Concerns over cleaning and blending initiated the Grain Quality Improvement Act of 1986. In essence, many people believed that there was something inherently wrong about reintroducing material that had been removed from the grain. The act prohibits: 1) recombining or adding dockage, dust, or foreign material to any grain at export facilities; 2) blending different kinds of grain; and 3) adding broken kernels from one grain to another.

Cleaning

Cleaning wheat in commercial handling facilities is normally limited to removing dockage, insects, and to a limited degree shrunken and broken kernels. In corn, cleaning regulates the amount of broken kernels and foreign material; in soybeans, it controls the amount of foreign material and split soybeans. The handling and harvest properties of each grain, along with the location of grain cleaners, dictate the amount of cleaning required to meet various contract specifications. For example, corn harvested at low levels of broken corn and foreign material but high moisture must be dried and, due to its inherent nature, it breaks up during each handling.

Thus, cleaning corn to remove broken corn and foreign material is required at each handling in order to meet contract specifications and avoid discounts. As most dockage in wheat is generated during harvest, and as normal handling does not cause significant dockage increases, cleaning is not required each time wheat is handled. Soybeans, on the other hand, fall somewhere in between regarding breakage susceptibility and the amount of cleaning required at each handling.

Data are not available on the number of cleaners on v. off farms. The number on farms is probably related to the particular crop, the amount of on-farm storage, and the number of operations performed on the crop at the farm level. For example, most corn is stored and dried on farm. In wheat, on the other hand, drying is not required and the amount of dockage can be regulated by the combine. Therefore, significantly fewer cleaners are probably found on wheat then on corn farms.

Principles of Cleaning

The most common types of cleaners are mechanical screening and scalping devices. Scalpers remove material larger than grain and allow the grain and fine material to pass through. Smaller screens are used to retain the grain and allow small material to pass through. Screens may be stationary, with grain flowing or being swept along them, or they may be shaken or rotated. Cleaning grain using screen and scalping devices makes a particle size separation. Screen sizes vary by commodity, but usually coincide with the sieve sizes used in each Official U.S. Standard for Grain to define the respective factors.

Other types of cleaning devices use aspiration. This separates grain from less dense material by drawing air over a falling grain stream and pulling the lighter material into a cyclone-type separator. In addition to removing fine material, aspiration has also been found to be effective in removing insects from wheat. Cleaners using gravity tables (seed weight separation) and length graders (seed size separation) are used by seed conditioning plants. Screens and aspirators, however, are the only methods with the throughput capacity needed for modern bulk handling facilities.

The Official U.S. Grain Standards for corn and soybeans use particle size to discriminate between whole and broken kernels and foreign material. In wheat, particle size separations and aspiration are used to separate all matter other than wheat. This process does not distinguish between whole or broken kernels. The scalping process removes material considered to be foreign to grain (i.e., stems, chaff, cobs, etc.) and also does not distinguish between whole or broken grains. Screening removes smaller foreign matter, dirt, weed seeds, etc., but depending on screen size can also separate whole, broken, or split grains.

When establishing screen sizes, the relationship between removing unwanted foreign material and removing broken, split, or shriveled grains is important. Whenever grain is cleaned by screening to remove foreign material, screen size has an impact on the amount of broken or shriveled grains that will ultimately pass through, but no matter what screen size is established, screens cannot remove everything. For corn, the common screen size is a 12/64-inch round-hole sieve. This size has recently caused much discussion since it removes a large percentage of broken kernels. It is generally agreed that scalpers remove unwanted foreign material, but much debate has centered on the value of the broken grain removed at the same time. Since cleaning is intended to remove material that is lower in value than the remaining grain, setting screen size, especially in corn, is a balance between separating material that may have value from material that is of no value and that may cause quality deterioration.

A more recent discussion on setting screen size centers on the particle sizes that form spoutlines. Recent studies have shown that crevices between kernels act like a screen. Fine particles small enough to fall into these crevices form spoutlines. One study found larger particles in corn spoutlines than in soybean spoutlines, and that spoutlines essentially do not exist in wheat. It concluded that the best screen sizes for corn and soybeans would be ones that will remove all particles of a size to form spoutlines.

Aspiration, which is predominantly used to clean wheat and in some areas has been used to remove insect infestations, has been effective in removing the lighter, less dense material normally considered to be of no value. The problems associated with the percent and value of broken and shriveled kernels removed, therefore, would appear to be less. However, density decreases with particle size (31,68), and aspiration cleaning will produce cleanings of lower density than screen cleaning for the same percentage of material removed. One study found that low-density whole corn kernels are not of inferior feed value (28), but more recent studies show that they are a detriment to milling operations (53).

Another study measured the nutritive value of various corn particle sizes (30) (table 7-8). No particle size discriminated by nutrient content, nor was nutrient content dramatically reduced with decreasing particle size. On the other hand, the majority of the dust and inert material was concentrated in the sizes 8/64 inch and below, while weed seeds were mostly between the 10/64 and 6/64 size.

The relationship between screen size and the value of the material removed is further complicated by the fact that smaller particle sizes contain less available starch to support mold growth (30). However, studies have also shown that concentrations of broken and fine material are conducive to insect growth and reduce airflow during aeration. Broken corn between the 16/64 and 8/64 sieves has been found to be more biologically active than the sieve sizes currently being considered for inclusion in the Official Standards for Corn (8/64 and 6/64) (30). The debate continues, therefore, on what should be removed and how much, and the material's relationship to setting grade limits and its effect on storability.

Current Procedures

Cleaners in commercial facilities are normally placed after the final elevation. Cleaning, therefore, is performed during loadout unless the grain is being cleaned to enhance dryer performance or is going into storage. On-farm cleaning, when done, is primarily to improve dryer performance.

Introducing clean grain to the dryer has the following advantages: 1) it results in more uniform airflow in the dryer and thus a more uniform moisture content of the dried grain, 2) it decreases the static pressure (airflow resistance) of the grain, thus increasing the airflow rate and dryer capacity, 3) it eliminates the drying of material that deleteriously affects final grain quality, and 4) it results in less air pollution (55).

Obviously, cleaning before drying also has some disadvantages. It requires additional investments in cleaners, the handling of wet broken corn and fine material, and the rapid sale of wet, easily molding material; it also results in some dry matter loss. Although the advantages of precleaning wet grain are fairly well understood by dryer operators, most do not do it. The quality of U.S. grain would improve substantially if precleaning was adopted (21).

Commercial cleaning requires high flow rates. Gravity or vibrator screen cleaners with

Table 7-8.—Nutritive Value of Corn Fines, by Particle Size

	Size range, 64th-inch						
Property	Whole corn	15-12	12-10	10-8	8-6	6-4.5	<4.5
Protein, percent dry basis	10.20	10.06	10.35	10.38	10.44	10.97	12.27
Oil, percent dry basis	4.47	3.86	4.25	3.40	2.48	2.43	2.43
Fiber, percent dry basis	2.24	2.34	2.64	2.85	3.51	4.24	5.91
Digestible energy, Kcal/lb	1,785.80	NA	1,717.30	1,691.50	1,660.50	1,631.90	1,610.80

NA – not available.

SOURCE: L.D. Hill et al., "Changes in Quality of Corn and Soybeans Between the United States and England," Special Publication No. 63, Agricultural Experiment Station, University of Illinois, Urbana, IL, 1981.

capacities up to 40,000 bushels per hour are the norm. The general configurations of cleaning systems are found in commercial facilities. First, the entire grain stream can be passed through the cleaner, with the throughput adjusted to produce the desired amount of material in the cleaned product. Alternatively, the grain stream can be overcleaned and the clean out metered back as required.

Second, the entire grain stream can be cleaned using a screen larger than the size required. The cleanings can either be recleaned to remove smaller material or reintroduced directly. This option is particularly useful when handling both corn and soybeans because it allows the facility to use corn screens, thus reducing the time and costs associated with changing screens. Third, the grain stream may be divided so that only part is cleaned and part left uncleaned.

All these designs are useful only if part or all of the grain exceeds desired levels. This may not occur at the first point of sale. Studies on handling breakage indicate that for corn, about 0.5 percent broken corn and foreign material, as defined by a 12/64-inch round-hole sieve, is created at each handling. This percentage could be higher or lower, depending on the particular handling facility and the drying method. Breakage susceptibility in wheat is far less.

Once inert material such as stems, pods, cobs, weed seeds, dirt, and chaff is cleaned out, no further cleaning is required. However, depending on the type of grain and its susceptibility to breakage, breakage will occur at each handling throughout the marketing chain. Thus corn and soybean cleaners are located throughout the marketing chain and in every export elevator, whereas wheat cleaners are located closer to the first point of sale and, except in a few instances, are not found at export elevators.

The amount of cleaning is dictated by the limits established by official grades, subsequent discounts for particular factors, and storability. For corn and soybeans, official grade limits are not normally exceeded at the first point of sale. As these commodities move through the marketing chain, however, they must be continually cleaned in order to meet grade limits.

Wheat dockage levels delivered by the farmer to the first point of sale are purchased, with dockage being deductible as a reduction from weight. Cleaning wheat to remove dockage at this point and throughout the marketing chain is therefore strictly a function of economics and, in many instances, quality is better regulated through blending instead.

In practice, four basic economic factors determine whether wheat should be cleaned or not:

1. the cost of cleaning,
2. the price of screenings,
3. dockage levels, and
4. the cost of transportation.

A 1987 publication by North Dakota State University reported on the results of its yearly survey of elevator operators in that State (16). Of 168 elevator managers surveyed, 159 indicated that wheat was cleaned prior to shipment. They also indicated that incoming harvest wheat was cleaned when dockage levels reached on average 2.6 percent. Wheat shipments exceeding the 2.6 percent average were cleaned down to an average 0.9 percent. After harvest, incoming dockage exceeding an average 2.1 percent were cleaned down to an average 0.8 percent.

The North Dakota survey also indicated that the cost of cleaning can range from 2 to 5 cents per bushel, depending on cleaner capacities (16). Since dockage is treated as a deduction to weight, transportation costs to the final destination and price for cleanings are critical when determining the economics of cleaning. Transportation rates as well as the price for cleanings have decreased in the mid-1980s. Multiple-car and unit-train shipments have reduced the cost of moving wheat from the Northern Plains States to the Pacific Northwest. When the cost of cleaning, transportation rates, and the price of cleanings are evaluated, the survey indicates that it is not economical to clean wheat in these areas unless dockage levels exceed 2 percent.

The amount of grain cleaning prior to storage revolves around the risk of grain deterioration as a result of mold and insect invasions and the costs associated with maintaining quality. The effects of mold and insects on grain quality, along with technologies used to maintain quality, are discussed in the section dealing with storage and handling technologies.

Fine material segregates in spoutlines, as discussed in other sections of this chapter. Hall (25) found that materials that pass through a 12/64-inch round-hole sieve segregate in spoutlines, while larger pieces rolled with the whole corn to the sides. This phenomena affects aeration since fine materials have higher airflow resistance than whole kernels, and the air detours around them, commonly causing overaeration.

Several other investigations on the effect of corn particle size on aeration have been conducted. Small pieces (12/64 inch in diameter and smaller) cause the most increase in airflow resistance during aeration, and the finer the particles, the more the resistance. However, the level of broken corn and foreign material present in the grain mass can also have an impact. Even though the impact of cleaning on dryer performance and storage technologies is well known, moisture content is the principal factor in decisions regarding storability and dryer performance, not cleaning.

New and Emerging Technologies

Aspiration cleaning is a relatively new technology being used in some wheat-producing areas to clean grain and remove insects. Multipass systems, in which grain is aspirated several times at progressively increasing air velocities, have improved efficiency. Aspiration cleaning will become more prevalent if clearly demonstrated to be capable of cleaning at normal production handling rates.

Several cleaners in Europe are arranged to use centrifugal force rather than vibratory motion or impact to cause screen separation. The one offered in the United States also has aspiration before the screens. The principle was designed to preclean wet grain before drying. With the majority of corn being dried on-farm, it is doubtful that a moderate capacity (4,000 to 10,000 bushels per hour) cleaner will penetrate the commercial market. However, it is a viable concept for preparation of specialty shipments and might be useful to clean corn after commercial drying.

Rapid sensing systems for physical properties open possibilities for on-line control of cleaning systems. No commercial devices of this type are available, but investigative work is being done.

Blending

Blending can be defined as mixing two or more grain lots to establish an overall quality that may or may not be different from any one individual lot. Blending occurs for three reasons:

1. there are economic incentives for grain to be at a specific quality, no better or worse;
2. the uniformity of the reblended product makes it better suited for handling, storage, or utilization; and
3. sometimes an aspect of a particular process requires a specific quality or range of quality in preference to other possible qualities.

Except for factors such as protein and falling number in wheat, the present U.S. marketing system does not normally emphasize user properties, so the first two explanations are the most applicable. However, as more user properties (e.g., protein, oil, and starch) become trading factors, situations will occur when a blended product will be more valuable to the user.

The central issue in blending is whether it has a positive or negative impact. The list of important quality factors can be divided into two categories: those that are defects (or will cause defects) and those that are specially tied to individual end use. The line is not always clear, but defect factors are of negative value to all users whereas user-sensitive factors will be evaluated differently, even oppositely, by different users. Primary examples of defect factors are foreign material and damaged kernels. As all defect factors have negative value, blending these factors will not improve the value of grain (29).

Blending can be neutral or even beneficial for user-sensitive factors such as protein in wheat. If the value of factors can be determined on a linear continuous scale (e.g., protein in wheat and soybeans and oil in soybeans), then deliberate blending will neither help nor hurt. However, if the premium scale is not proportionally sensitive, then blending may may not be beneficial. Processes may also have to be adjusted to make the most use of varying qualities (e.g., steeping time in wet milling or protein in wheat milling), which means that uniformity within the shipment as evidenced by test results clustered around some mean value will be preferred to random distributions.

Principles of Blending

Many States contribute to national wheat, corn, and soybean production. Weather, genetics, and agronomic differences virtually assure quality differences within and across crop years and contribute to the lack of uniformity within a particular grain. These differences exist for whatever factors are used to describe quality. For example, if an importer were to purchase wheat today, the shipment could be comingled with a multitude of varieties, from several regions, covering several crop years.

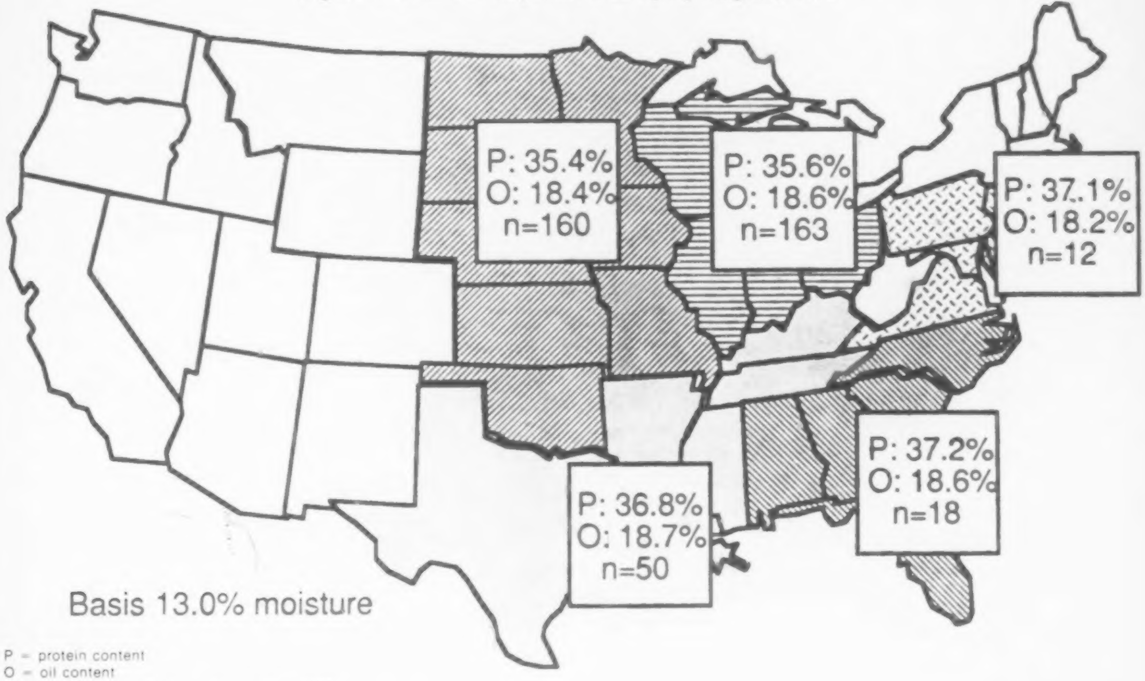
As intrinsic factors start to be measured and taken into account in the marketplace, the regionality problem will be magnified. Figure 7-16 presents data on regional soybean protein and oil. Blending will have to occur if fixed specifications are set. If soybean protein and oil are priced on a continuous scale with no mandatory targets, growers in some areas will face discounts relative to growers elsewhere.

The basic mathematics of blending are relatively simple. The quality of a blend is the weighted average of the qualities being blended. The application is straightforward when two or fewer are involved. If several characteristics have economic value, however, then a profit function must be set up in terms of all relevant factors. The optimum blending proportion is the one that yields maximum profit. Many other considerations—storage space, market expectations, shiploading plans, and so on—must be included. Linear program methods have been used to analyze complex blending problems (41).

If more than one factor is being controlled, then the blend is most easily optimized if the one quality factor is concentrated in all grain lots used in the blend. This minimizes the effect of blending for that factor and allows concentration on the others. When the levels for the factor are low, then concentrating on the individual factor being blended will minimize the number of secondary streams. This explains why cleaning and reblending broken grains and/ or foreign material is preferred over blending two grain streams of differing percentages. It is also easier to hold a uniform blend when controlling a small flow rate of pure foreign material, pure damage, or clean, high-moisture grain.

U.S. grain-handling facilities are designed to store large masses of relatively uniform grain of some intermediate quality, with small special storage for lots concentrated in one quality factor (high moisture, high damage, high protein, etc.), although to a lesser degree in spring and Durum wheat-producing areas. This is possible because the most heavily traded grades allow the majority of the grain to fall within broad limits and thus be stored en masse. As additional quality factors are introduced, this design and management philosophy will present more difficulties, since there will be more factors to consider in profit maximization. In-

Figure 7-16.—U.S. Soybean Quality by Region, 1986



P = protein content
O = oil content

SOURCE: American Soybean Association, 1987

trinsic factors cannot be as readily concentrated or manipulated as physical factors.

Current Procedures

Premiums and discounts can encourage or discourage blending and are set by merchants subject to buyers' needs and supply conditions. For example, high-damage corn is more likely to be directed to export for blending into No. 3 than to a domestic processor buying No. 2. Likewise, poorer quality soybeans are more apt to fit in No. 2 export cargoes than in No. 1 purchases by domestic processors. On the other hand, protein in wheat can be directed to either the domestic or the export market using protein premiums and discounts.

A case in point is protein content in spring wheat using March 1988 protein premiums and discounts in both the Pacific Northwest and Minneapolis markets. The base protein value for assessing premiums and discounts in both markets is 14 percent. In the Pacific Northwest, protein premiums of 3 cents were being paid for each 0.25 percent over the base, whereas 6-cent discounts were applied to shipments under the base. At the same time, in the Minneapolis market premiums of 5 cents were paid for every 0.2 percent over the base with discounts of 3 cents being applied for shipments under the base. With such a schedule, a shipper would be better off blending protein levels for shipment to the Pacific Northwest and shipping 13 and 15 percent shipments separately to the Minneapolis market.

Grain handlers do not solve complex mathematical formulas to adjust blending proportions as they move grain. Table 7-9 shows a typical example of four soybean lots being combined to make a U.S. No. 2 grade. The equal-proportions blend would not necessarily be the high-

Table 7-9.—Blending of Four Soybean Lots to Make U.S. No. 2, Maximum 13% Moisture

Lot	Moisture (percent)	FM (percent)	Damage (percent)	Value[a] (dollars per bushel)
1	11.5	1.0	1.0	6.00
2	14.5	1.2	1.0	5.82
3	12.5	1.0	5.0	5.94
4	11.5	4.0	1.0	5.88
Average value				5.91
Blend of equal proportions	12.5	1.8	2.0	6.00
Contract specification	13.0	2.0	3.0	6.00

[a] Based on typical discount schedules relative to U.S. No. 2. base price of $6.00/bu.

SOURCE: C.R. Hurburgh, "The Interaction of Corn and Soybean Quality With Grain Storage," background paper prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, 1988.

est profit one, but is quite common. If the foreign material were removed and reblended as pure foreign material, more wet soybeans (lot 2) and more damaged beans (lot 3) could be blended without exceeding specifications. Likewise, if lot 3 were more concentrated in damage, it would exert more effect on the damage percentage and less on other factors. Overall, however, profits from blending are possible only if the average quality of grain normally exceeds specifications. The closer the specifications are to the available average quality, the less the potential for blending.

Operationally, blending is accomplished with varying degrees of sophistication. At export, barge, and major inland terminals, grain is continuously sampled with a mechanical diverter as it is being loaded. Samples are analyzed and changes to the mix can be made. Generally, the facility manager will target quality somewhat better than the specifications to protect against the chance that normal variability in loading, sampling, and analysis will yield a result exceeding specifications.

Modern facilities have proportioning gates that control the flow of individual qualities to the blend. If the facility is equipped for any of the cleaning/reblending options discussed in the cleaning section, cleaner throughput and reblending rates will also be controlled from the loadout control center. Older facilities do not have continuous sampling and automated flow control.

Quality Factors Affected by Blending

Moisture.—The primary reason for moisture blending is purely economic, and it is most common at interior locations where high-moisture grain is more available. Handlers and growers routinely capitalize on cold weather to store moderate-moisture corn (up to 20 percent) and soybeans (up to 15 percent). Furthermore, carryover stocks from previous years are usually much drier than market limits, offering an opportunity for blending with fresh wet grain from the field at harvest. Moisture blending can cause grain deterioration, as discussed in the storage and humidity technologies section of this chapter.

Particle Size.—Blending for particle size factors has stirred the most controversy because these include dockage, foreign material, and dust. As discussed in the cleaning section, corn and soybeans break during each handling, creating foreign material and dust. This is compounded by the fact that corn breakage susceptibility increases about 40 percent for each 1-percent reduction in moisture (19). Soybean breakage susceptibility increases 22 percent for each 1-percent reduction in moisture (32). Breakage is not the critical factor in wheat. However, since dockage in many areas of the country is not removed, each handling generates dust, which is collected. Therefore, blending of these factors is essentially a defensive operation to minimize the economic effects of constant handling, breakage, and dust generation.

As mentioned in other sections of this chapter, as grain is loaded, fine material concentrates in the center of a grain mass and uniformly blended grain streams will not stay uniform once loaded because fine material segregates. No amount of blending will eliminate this problem.

Kernel Damage.—Blending damaged kernels is a purely economic operation that exists because normal damage levels are less than allowed in specifications. Corn is harvested with about 2 percent damaged kernels, soybeans normally with less than 0.5 percent, and wheat well within the limits of No. 1 (2.0 percent). Grade limits for damaged kernels in export shipments of No. 3 corn (7 percent), No. 2 soybeans (3 percent), and No. 2 wheat (4 percent) are wide enough to accommodate blending of any unusual or storage-damaged lots.

INTERACTIONS/FINDINGS AND CONCLUSIONS

Grain is a living, breathing organism and as such is a perishable commodity with a finite shelf life. The best harvesting, drying, storing, handling, and transporting technologies in the world cannot increase quality once grain is harvested. Each technology is a self-sustaining operation, but the way each is used affects the ability of the others to maintain quality. For example, if grain is harvested wet, not only will this lead to increased breakage during harvesting, but it means the grain must be dried. Improperly used dryers means more breakage and nonuniform moisture content. Moisture content, uniformity of moisture content, and the amount of broken grain and fine materials affects storability and can have an impact on the technologies used to maintain quality during storage. Therefore decisions made at harvest, as well as at each step thereafter, influence the system's ability to maintain and deliver a quality product.

As discussed throughout this chapter, grain moisture and amount of broken grain and fine materials stand out as the two critical factors affecting the performance of each technology.

Moisture

Moisture at harvest directly affects the amount of kernel damage produced through combining. For corn, physiological maturity is obtained at about 30 to 35 percent moisture. Although corn can be harvested at this point, it is damaging to the kernel's soft pericarp and is not recommended. In the Midwest, it is generally recommended not to harvest until the corn has field-dried to 26 percent moisture. However, obtaining a 26 percent moisture in the Northern States is not possible during wet fall harvest periods, and corn must be harvested at higher moisture contents or it will not get harvested at all.

Since cereal grains and oilseeds are harvested in the United States at moisture levels that are too high for long-term storage or even short-term storage and transportation, these commodities must be dried to acceptable moisture levels. Corn, harvested at 20 to 30 percent moisture, must be dried to 14 to 15 percent for safe storage. Wheat and soybean harvest moistures are substantially lower, with their safe storage levels marginally lower than harvest moisture. In certain regions of the United States, wheat dries naturally in the field. In some cases this is also true for soybeans.

The process of drying has a greater influence on grain quality than all other grain-handling operations combined. For superior grain quality, it is imperative to optimize dryer type and operation since half the corn crop is dried in continuous-flow, portable batch, and batch-in-bin dryers of the crossflow type. Of particular concern is the increase in breakage of corn and soybeans and the decrease in milling quality of wheat. Artificial drying of wheat and soybeans, however, is not frequently required.

The main dryer operating factors affecting grain quality are air temperature, grain velocity, and airflow rate. Operators can adjust the first two on every dryer and, on some units, can adjust all three. Collectively, the three conditions determine the drying rate and maximum temperature of the grain being dried, and thus establish the quality of the dried lot.

Over 80 percent of the United States corn crop is dried on farms. On-farm dryers fall into three categories—bin, non-bin, and combination dryers. Bin dryers are in general low-capacity, low-temperature systems, able to produce excellent quality grain. Non-bin dryers, the most popular dryer type, are high-capacity, high-temperature systems that frequently overheat and overdry the grain, and thereby cause serious grain-quality deterioration. Combination drying combines the advantages of both systems (i.e., high capacity and high quality) but requires additional investment, and is logistically more complicated. A switch by farmers from non-bin to combination drying would significantly improve U.S. corn quality.

Off-farm dryers fall into three classes—crossflow, concurrent-flow, and mixed-flow dryers. All are high-capacity, high-temperature units. In the United States, crossflow models are the most prevalent; they dry the grain nonuniformly and cause excessive stress-cracking of the grain kernels. Mixed-flow dryers are common in other major grain-producing countries; the grain is dried more uniformly in these, and is usually of higher quality than that dried in crossflow models. Concurrent-flow dryers have the advantage of producing the best quality grain; their disadvantages are the relatively high initial cost and the newness of the technology. A change from crossflow to mixedflow/concurrent-flow dryers will benefit U.S. grain quality.

Moisture content and uniformity within a storage facility are critical to maintaining grain quality, as demonstrated by the Allowable Storage Time Table for corn. The interaction between moisture, temperature, and relative humidity spurs mold growth, increases insect activity, and causes other quality losses. Basically, grain moisture in equilibrium with 65 percent relative humidity will support mold activity, but different grains will create the equilibrum relative humidity at different moisture levels. That is why wheat and soybeans cannot be stored at the same moisture content as corn. In the case of controlling insects, high moisture contents increases absorption of fumigants such as methyl bromide, requires an increase in dosage, and accelerates the breakdown of protective treatments such as malathion.

The equipment and methods used to fill a storage bin affect the performance of aeration systems used to control the effects of moisture/temperature/humidity. Dropping grain into the center of a bin causes a cone to develop, with the lighter, less dense material concentrating in the center (in spoutlines) while the heavier, denser material flows to the sides. This impedes airflow during aeration, and molds can begin to grow almost immediately.

In large horizontal storage areas, loading from the center or from a loader that is gradually moved backward through the center of the building as the pile is formed causes similar problems. If grain is piled over each aeration duct on the floor by moving the loading device back and forth, airflow will be greatly increased. However, airflow distribution is not as uniform as in upright bins. Some methods of filling piles also result in fine materials concentrating in local areas. These accumulations are more subject to insect and mold growth, and they divert airflow. But piles are difficult to aerate, and the shape of some restricts uniform airflow.

Nonuniform moisture levels can lead to spoilage in localized areas within a storage facility. Even assuming that moisture and temperature are uniform within a grain mass, they will not remain so over time. Moisture will migrate in response to temperature differentials. If the outside air is warmer than the grain, the circulation reverses, and the area of condensation is several feet under the grain surface, but still in the center.

The effect of moisture migration on storage is that grain assumed to be in a storable condition will not be. Cold weather migration primarily affects grain in land-based storage, causing deterioration as temperatures rise in the spring. Warm weather migration is particularly vexing for grain in transit both from cold to warm areas of the United States and from the United States through warm waters to foreign buyers. A barge or ocean vessel is basically a storage bin and will experience the same migration phenomena as land-based storage facilities.

Broken Grain and Fine Materials

Three factors—cylinder speed, moisture at the time of harvest, and amount of grain damage—are interrelated. In general, whenever grain is harvested, damage or breakage occurs. However, grain damage is much greater in each case on extremely wet or extremely dry grain. When grain is harvested at high moisture levels, the kernel is soft and pliable. Moist kernels deform easily when a force or impact is applied, and greater force is needed to thresh wet kernels than dry ones. Thus, wet kernels suffer more damage than drier kernels. However, drier kernels can break when the same force is applied. Therefore, optimal conditions exist for each grain.

In addition to grain breakage due to moisture content, factors such as weed control and kernel density, especially in wheat, also affect a combine's ability to harvest and deliver clean grain. Cutting below the lowest pod or wheat head inadvertently introduces some soil into the combine. Most soil is aspirated from the rear unless there are soil particles about the same size as the kernel, in which case they pass through the cleaning sieves with the grain.

Harvesting technologies normally remove material larger than the grain (such as plant parts) and material significantly smaller (like sand and dirt). Sloping terrain, however, can affect this process. Side slopes also create problems since the tendency is for material to congregate on the downhill side of the cleaning shoe.

The main factor affecting the combine's cleaning performance is the amount and type of weeds present in the field during harvest. Weed control is one of the most serious problems facing many wheat producers in the United States. This is also true for Southeastern U.S. soybean-producing areas, where a warm wet climate is conducive to weed growth. The amount of weeds affects not only yield, but also the amount of foreign material present in the harvested grain and the combine's ability to remove this material.

Combines are being modified to improve performance in weedy fields. In the case of wheat, kernel size has been decreasing, which complicates this modification. The trend toward smaller kernel size is a concern because the seeds of most grassy weeds are smaller and lighter than wheat. Thus, smaller wheat kernel size reduces the margin between wheat and weed size and, therefore, increases the difficulty of cleaning within the combine.

As discussed in the drying technology section, rapidly drying moist grain with heated air causes stress cracking. The drying operation itself does not cause grain breakage, but can make grain more susceptible to breakage in later handlings. Cleaning grain before it reaches the dryer can improve dryer efficiency. Introducing clean grain to the dryer:

- results in a more uniform airflow in the dryer and thus a more uniform moisture content of the dried grain;
- decreases the static pressure (airflow resistance) of the grain, thus increasing the airflow rate and dryer capacity; and
- eliminates the drying of material that detracts from final grain quality.

Obviously, precleaning also has disadvantages. It requires additional investments in cleaners, the handling of wet broken corn and fine material, and the rapid sale of wet, easily molding material, and it results in some dry matter loss. Although the advantages of precleaning wet grain are fairly well understood by dryer operators, most do not preclean. The quality of U.S. grain would improve substantially if precleaning were adopted.

Mechanical damage during handling results in grain breakage, which produces broken grain and fine materials. This causes a decrease in quality, greater storage problems, and an increase in the rate at which mold and insects invade stored grain.

Research has shown that breakage in handling is more significant for corn than for wheat and soybeans. Higher moisture content and higher temperatures prove to be the optimum conditions to minimize breakage but are opposite of the optimum safe storage moisture and temperature. The effect of repeated handlings on grain breakage is cumulative and remains constant each time grain is handled or dropped. This is true whether or not broken material is removed before subsequent handlings.

The impact of grain breakage and fine materials on all aspects of the system has resulted in the need to clean grain. Cleaning wheat in commercial handling facilities is normally limited to removing dockage, insects, and to a limited degree shrunken and broken kernels. For corn, cleaning regulates the amount of broken kernels and foreign material, and for soybeans, the amount of foreign material and split soybeans.

Cleaning corn to remove broken corn and foreign material is required at each handling in order to meet contract specifications and avoid discounts. For wheat, however, the majority of the dockage is generated during harvest and normal handling does not cause significant increases. Therefore, cleaning is not required at each handling. Soybeans, on the other hand, fall somewhere in between regarding their breakage susceptibility and the amount of cleaning required at each handling.

The amount of grain cleaning prior to storage involves the factors of risk to grain deterioration as a result of mold and insect invasions and the costs associated with maintaining quality. In the case of fumigation: broken grains, grain dust, and other fine materials have the greatest effect on the performance of insect control interventions. When a protective treatment is applied, grain dust may absorb much of the insecticide, which reduces the effectiveness. Likewise when a fumigant is applied, concentrations of dust and fine material may require increased dosages to penetrate the grain mass. Dust also inhibits penetration of fumigant gases and causes the gas to channel so that penetration is slow or stopped in certain parts of the grain mass.

Ability of System to Maintain Quality

Technologies are in place to harvest, maintain, and deliver quality grain. Each technology must be used, however, in a manner conducive to maintaining grain quality.

Although data indicate that nearly any combine can deliver acceptable quality, farmer-operated combines tend to have higher levels of grain damage than the combine should deliver. From a technology standpoint two areas need emphasis:

1. greater education efforts to help operators better understand the interactions of cylinder/rotor speed, concave openings, fan speed, and sieve openings with grain quality and grain losses; and
2. more monitoring devices and possible automatic controls on combines to help operators adjust or fine tune the combine.

Weed control and its relationship to kernel size and density are critical to optimum combine performance. Unless new technologies addressing this area are developed or better weed control measures for use by the farmer are forthcoming, the combine's ability to harvest and clean grain will continue to present problems.

A significant improvement in grain quality can be obtained by optimizing the dryer operating conditions of existing crossflow dryers, by precleaning wet grain, by selecting the best grain genotypes, and by installing automatic dryer controllers.

Molds will grow on any kernel or group of kernels that provide the right conditions. Therefore, moisture content and moisture uniformity within storage facilities are critical to maintaining grain quality. Maintaining low temperatures and moisture levels in grain are the principal ways to preserve grain quality and prevent damage from molds and insects. Aeration is also a very effective tool. The rate of development of both molds and insects is greatly reduced as temperature is lowered.

Many storage bins, especially on the farm, are equipped with aeration systems that are often not used effectively. Farm storage bins, especially smaller and older ones, often are not aerated. Small bins will cool or warm with the changing season quickly enough that moisture condensation may not be a serious problem. A majority of farm aeration systems are either not operated at all or not used enough. The most common problem is not running the fans long enough to bring the entire grain mass to a uniform temperature level. If a cooling front is moved through only part of the grain, a moisture condensation problem is likely at the point where the warm and cold grain meet.

In addition to aeration, the turning and transfer process mixes grain and contributes to a more uniform moisture and temperature. In facilities not equipped with aeration, turning has been the traditional means of grain cooling. However, turning requires much more energy to cool grain than aeration does, and it can contribute to physical damage by breaking the kernel.

Turning grain cannot be performed in horizontal or pile storages because of the difficulty in unloading and moving the grain. In order to turn grain, a handling system must have empty bins connected by a conveying system. This is not the case on most farms.

Most grain storage facilities provide a natural habitat for stored-grain insects even when the facility is empty. Grain residue in floor cracks and crevices, wall and ceiling voids, and ledges provide an ample supply of food to sustain several insect species. Thorough cleaning is the first and most effective step toward preventing insect infestation of freshly harvested grain. Because insects live from season to season, cleaning and removing trash and litter is important. Also, a thorough cleaning should precede any insecticidal treatment of storage facilities if the full value of the treatment is to be expected.

For several reasons—such as remoteness of farm storage facilities, small amounts of grain to be treated, and lack of information—farm storage facilities are inadequate to receive an insect control treatment. Therefore, when grain that has not received a properly applied treatment is marketed, it becomes mixed with noninfested grain and magnifies the problem, thus creating greater loss and the need for more expensive and time-consuming remedies.

The high-speed, low-cost U.S. grain system does not readily accommodate special quality needs. While these needs can be met by slowing belt speed, installing and using cleaning equipment, eliminating unneeded handlings, and preserving the identity of grain, most of these actions increase costs.

All the factors affecting quality just discussed —nonuniform moisture, moisture migration, temperature and humidity, insect invasion, and mold development—have an impact on grain quality during shipment. No mode of transportation is equipped with aeration, nor can grain temperatures and corrective actions be taken during shipment. And moisture migration can be more dramatic during shipment since grain can undergo several outside air temperature and humidity changes. This is especially true when grain is loaded in a cold climate and transported through warm water rather quickly to a warm humid climate. Therefore, moisture uniformity is critical to maintaining quality during shipments.

The interactions between technologies regarding moisture content and breakage on grain quality are evident. Each technology is capable of preserving grain quality. Once inert material such as weed seeds, dirt, stems, cobs, and so on are cleaned out of grain, no further cleaning is required. But grain, especially corn, must be cleaned to overcome breakage due to handling in the system and is inevitable. Once grain quality deteriorates at any step in the process, it can never be recovered. As demonstrated by the Allowable Storage Time Table for corn, shelf life is a time line with a certain share expended at each storage condition. Once this time has passed, there is no way to recover what has been lost.

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Chapter 8

Analysis of U.S. Grain Standards

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Chapter 8

Analysis of U.S. Grain Standards

The evaluation of the current U.S. inspection system, possible alternatives, and proposed changes in grain standards requires principles on which to base the criteria for change. This chapter sets forth those principles. No attempt has been made to assess the economic consequences of the alternatives because they depend on the market response to the actions of many individual companies involved in marketing grain. Uniform, accurate, and objective quality measurement should be based on the logic and consistency of the system, not on the economic benefits to individual companies or sectors (2).

Marketing efficiency requires a system of descriptive terms that enable purchase and sale by description. The sale of millions of bushels of grain by telephone and telex would not be possible without the common language on quality and value provided by U.S. grain standards. Since most commercial transactions use only one or two grades, the many diverse qualities produced by nature and varying farm practices are combined into a few relatively uniform standardized categories during the marketing process. The move toward a uniform product, however, conflicts with the profit-maximizing principle of product differentiation.

Private gains from product differentiation are offset by aggregate losses in the efficiency of market transactions. It is not surprising to find individual exporters and domestic grain handlers unwilling to support change despite evidence that it would benefit the industry as a whole. Measures of oil and protein in the soybean standard may logically meet opposition from individual firms whose profits depend on being the first to identify sources of soybeans with oil content above the average for that crop year.

Uniform grain standards provide all buyers and sellers with equal access to information on value. This forces competition on the basis of operating efficiency, rather than on control of information. The inability to gain acceptance of voluntary standards prior to the 1916 United States Grain Standards Act (USGSA) can be traced to conflict between market opportunity for individual firms through product differentiation and the efficiency of marketing associated with product uniformity. Only through nationally enforced grain standards could individual firms reap the benefits of industrywide market efficiency emanating from uniform standards.

The 1916 USGSA and subsequent amendments and regulations have established two areas of responsibility for the Federal Grain Inspection Service (FGIS) of the U.S. Department of Agriculture (USDA):

- to establish uniform grades and standards, and
- to implement national inspection procedures to assure accurate and unbiased results.

INSPECTION AND TESTING

Grain can be inspected many times as it moves from the farm to its ultimate destination, as demonstrated by figure 2-2 in chapter 2. Normally grain is tested for one or more important characteristics each time it is moved into or out of a grain elevator. The number and type of tests performed vary from those provided for in the grain standards to specific end-use tests, such as breakage susceptibility in corn, to laboratory tests like dough handling properties of flour.

No single national policy outlines what tests will be performed or who will perform them. The USGSA requires that grain standards be developed and used when marketing grain. The standards provide tests covering such items as moisture content, bulk density, and amount of impurities, but do not specify who will perform the tests or what tests will be conducted on grain moved within the United States. In fact, two USDA agencies have been authorized by Congress to provide testing services, using the grain standards, on grain moving domestically. Except for protein content in wheat, other tests such as for protein/oil quantity and quality and specific end-use tests are performed at the discretion of the ultimate user. The only mandatory testing is performed by FGIS on export grain.

In practice, grain traded between two companies is normally tested by FGIS or one of its affiliated agencies, using tests contained in the grain standards. However, some domestic processors and nearly all grain companies that buy farmer-owned grain purchase it on the basis of tests performed by their own personnel. These groups, except in cases where a particular buyer requires additional tests, normally use some or all of the tests provided for in the grain standards. In other cases, in-house testing is used by grain companies on shipments moving between their own facilities.

FGIS Inspection

The inspection system mandated by USGSA currently consists of FGIS offices with Federal inspectors located at major ports, 72 designated State and private agencies located in the interior of the United States, and 8 delegated State agencies at ports not serviced by FGIS. FGIS administers field offices throughout the country to oversee the activities of State and private inspection agencies.

All nonfederal employees employed by State and private agencies authorized to perform inspection on behalf of FGIS must pass examinations on grading proficiency and must be licensed. These individuals can be licensed to inspect one or more of the grains for which standards have been established. In no instance, however, can individuals perform official inspections unless they hold a valid license for that grain.

In addition to developing standards and providing inspection services, FGIS:

- develops and publishes inspection procedures,
- evaluates and approves equipment for use during inspection,
- monitors inspection accuracy of FGIS employees and licensed inspectors,
- periodically tests sampling and inspection equipment for accuracy,
- provides appeal inspection, and
- responds to complaints regarding service.

FGIS also audits its own activities to ensure that service is being provided on a nondiscriminatory basis and that no licensed individual has a conflict of interest.

Non-FGIS Inspection

Inspection services using grain standards established under USGSA may be performed by grain company employees or by private companies not affiliated with FGIS. Grain received from farmers is seldom graded by FGIS or FGIS-licensed inspectors but by employees of the elevator or processing firm.

The standards established under USGSA are generally used as the basis for inspection by company employees. FGIS procedures may or may not be followed, based on individual company policy. Equipment and inspection accuracy are not monitored unless the company has established an internal monitoring program. In many cases, company inspectors compare their test results to those obtained by FGIS or FGIS-licensed inspectors on the same grain in an effort to ensure accuracy. Either buyer or seller may request FGIS or an FGIS-licensed inspector to check the grain if the results of the private inspection are in question. However, neither party is required by law to abide by the inspection results.

Export Inspection

USGSA requires that all grain being exported be inspected by FGIS or a FGIS-delegated State agency. The only exceptions are for grain moving into Canada and Mexico by land carrier and for small exporters who ship less than 15,000 metric tons in a given year.

Notwithstanding this requirement, importers often request private companies in the United States to represent their interests and inspect the grain as it is being loaded. Such inspections can include checking for grade as defined by USGSA grain standards or for factors not covered by these standards, such as falling number in wheat or oil and protein in soybeans. When private companies perform inspections using the grain standards, two groups issue certificates—FGIS and the private company.

Samples obtained by private companies are often submitted to FGIS for analysis and grade, and results from FGIS are then used as the basis for the private company's certification. In other instances, private company inspectors actually perform the inspection. Settlement in most instances is based on the results provided by FGIS or a FGIS-delegated State agency. In rare cases settlement has been based on the private inspector's results or destination grades.

Testing Technologies

Since no single policy exists for inspecting grain, no one group is responsible for developing and overseeing the tests and equipment used. FGIS provides independent, third-party services using tests contained in the standards. Other tests such as for protein content and falling number tests in wheat, aflatoxin in corn, and ethylene dibromide residue are also provided. All tests done under the authority of FGIS are regulated in that the equipment must be approved, procedures for its use developed, and the accuracy of results monitored.

Tests provided under the authority of the Warehouse Division of the USDA, on the other hand, are not regulated to the same degree. No requirements for type of equipment, procedures for its use, or monitoring of equipment accuracy have been developed under this program.

In some instances, individual States have developed criteria for approving equipment and monitor the equipment's accuracy. Professional societies such as the American Oil Chemists' Society and American Association of Cereal Chemists develop criteria for approving tests, publish performance procedures, and establish programs to ensure equipment accuracy. Many tests covered by professional societies are not in the grain standards.

Regardless of which tests are performed and who performs them, several factors are important. These include instrument precision and standardization, calibration, the choice of reference methods and traceability to standard reference methods when developing rapid objective tests, and natural error resulting from sampling.

Standardization

The term standardization means that a measuring device has been adjusted to be in fundamental agreement with a universally accepted standard and that ongoing efforts are made to keep it in agreement (4). Standardization is vital to fair trade and will be even more important as technologically advanced testing equipment is introduced into the marketplace. The validity of a commercial measurement is judged by comparing it with a more stringent method that is accepted as determining the true value. The standard is the base method defined as being the true value. Working standards are devices and methods used to actually validate an individual test instrument. For dimensional measures such as mass, time, and volume, the reference standards are very precise. The procedure of matching routine devices against working standards and working standards against reference standards introduces little variability.

Probably the most visible example of standardization is the weights and measure program coordinated by the National Bureau of Standards (recently renamed the National Institute of Standards and Technology* (NIST)) of the Department of Commerce in conjunction with the National Conference of Weights and Measures. NIST develops specifications for instrument precision and accuracy along with scale tolerances, and maintains national standards. Scale testing agencies follow NIST procedures in performing periodic testing using field standards that can be traced back to the NIST national standard. In the case of grain measures other than weight, no single national organization exists for standardizing tests.

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*The National Bureau of Standards was recently renamed the National Institute of Standards and Technology (NIST) with the passage of the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418) as of August 1988.

Measuring grain quality is difficult to standardize because the true answer is not always known, as in the case of characteristics such as moisture, protein, and oil content. The reference method is therefore defined rather than proven. Choosing the reference method, however, can be difficult since it can also be as variable as the instruments themselves. For moisture, the standard reference is the air-oven method; for protein, it is the kjedahl procedure.

The kjedahl procedure for determining protein is internationally accepted and used. Currently, protein can be determined rapidly by using near-infrared-reflectance analyzers (NIR). These instruments measure reflectance readings at various wavelengths. The precision (repeatability) of the kjedahl procedure is ± 0.15 and for NIR it is ± 0.10. Therefore the NIR is more precise than the kjedahl, but after standardizing NIR to the kjedahl procedure, the results obtained with NIR are ± 0.2 to the kjedahl.

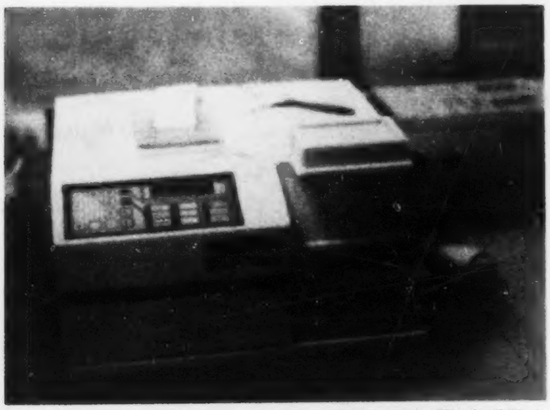


Photo credit: OTA Staff Photo

The near-infrared-reflectance analyzer (NIR) is the most advanced rapid objective testing technology. It currently is used to measure protein content in wheat. It will soon be used to measure oil and protein content in soybeans and corn protein.

In the case of moisture. choosing a reference method is more difficult since no one method is universally accepted. As on electronic moisture meters, FGIS has approved the Motomco brand meter for its testing program and calibrates it to the air oven. In States that do not enforce moisture meter accuracy or that allow different sets of calibrations to be used, several types of meters test 1.0 to 1.25 percentage points higher than the air oven and the Motomco. In addition, some meters used on farms are less accurate than those used by industry (5). This could result from the fact that not all manufacturers standardize to the air oven since there

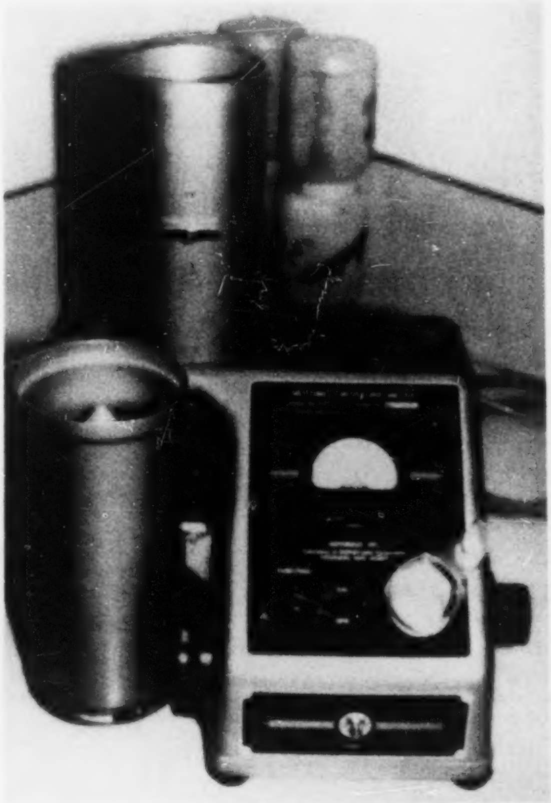


Photo credit: U.S. Department of Agriculture

The Motomco brand moisture meter is approved by FGIS for its testing program. In States that do not enforce moisture meter accuracy, several types of meters test up to 1.25 percentage points above the Motomco.

is no legal requirement to do so. As all oven methods are empirical, relying on weight loss that is assumed to be water, varying oven parameters will give varying results. Most international buyers use an oven method standardized to the Karl Fisher titration method. In the United States, this is not the case, and some feel that the United States is underestimating corn moistures by as much as 0.7 percent.

Further difficulties arise in standardizing tests when subjective measurements are involved. Results for many of the current tests contained in the grain standards are performed by visual and sensory evaluation and rely on human judgment. FGIS monitors its own accuracy and has developed visual aids as the basis for determining many visual tests, such as the degree of damaged kernels. These types of tests are difficult to standardize, and accuracy can vary widely especially when the same tests are performed without using FGIS visual aids or being subjected to FGIS oversight.

Calibration

In addition to having standardized tests, the equipment used to determine grain quality must be calibrated to standard reference methods. The calibration must always contain the full range of properties and equipment variations that will be encountered in general use, so that the instrument will not be overly sensitive to inevitable variations. However, the major calibration issue in grain testing is the pervasive variability of these tests. Calibration is further complicated by having to use actual grain samples to calibrate instruments, which introduces sampling variation independent of analytical error. As discussed, both the instruments to be calibrated and standard reference methods are subject to error. Changes in grain properties due to climatic variables complicate the problem of obtaining truly representative sample sets. In addition, as with NIR analyzers, units of the same brand are not identical, which means that the same calibration constants cannot be universally used. It should be noted that NIR calibrations require continuous monitoring for accuracy. Lack of monitoring contributed to the recent controversies over the accuracy of FGIS wheat protein testing.

The chain between the instrument used in the field to the standard reference method is referred to as traceability. The more steps there are in the traceability chain, the more chance there is for compounding random errors from one step to the next. In the case of moisture, for example, a standard meter in the main laboratory is standardized to the air oven, standard meters in the field can then be checked to the standard meter in the main laboratory, and field-standard meters can be used to check individual meters. Minimizing the number of comparison steps in the traceability chain may or may not maximize accuracy, depending on the actual size of the random variations.

Source of Testing Errors

Since any test result is based on a small sample that represents the entire population, test sample portions are subject to bias and variability, and any test result is really only an estimate of the properties of the entire population. The types of variation can be described as random and nonrandom. Nonrandom variation occurs from uneven distribution of grain properties, improper sampling procedures, and inaccurate measurement. Random variation is natural and unavoidable, since each grain kernel differs from all others.

If a load of grain is homogeneous, the closeness of the test result to the actual condition is governed by the laws of probability. The sample size required to produce a result that has the desired probability of approaching the actual condition of the grain can be calculated. To increase the probability, additional quantities of grain must be obtained or the size of the sample actually tested must be increased. For example, at a 90-percent confidence level a test portion size will produce results within a defined range. To narrow the range, a larger portion is required or more than one analysis must be performed to increase the accuracy of the result.

When setting portion sizes, the frequency of occurrence within a grain mass must also be considered. For example, aflatoxin in corn can affect only a few kernels in a grain mass and in order to detect levels of 20 parts per billion, which is the limit established by the Food and Drug Administration (FDA), 10 pounds of corn should be examined. This compares to only 2.5 pounds of grain required to determine the weight per bushel. (For additional information on aflatoxin testing technologies see box 8-1.)

Uneven distribution in a load of grain is more of a nonrandom error problem with some characteristics than others. For example, variance in weight per bushel—even though it can fluctuate within a load—is normally not that great. Moisture, on the other hand, can vary due to mixing or flow characteristics of damp and wet corn. Other factors, such as fine material, segregate and cause uneven distribution within a load. The method and type of sampling is therefore critical to obtaining a truly representative sample. Other nonrandom errors involve inaccurate measurements from incorrectly calibrated and maintained instruments, from human error, or from not following correct procedures.

Knowledge of the source of the variation is critical for assessing and improving the accuracy of test results. For example, improving moisture meter precision is an unnecessary effort because it contributes less than 10 percent of the total variability associated with the test (4). Moisture measurement errors arise mainly

Box 8-1.—Testing Technologies for Aflatoxin

Aflatoxin, a known carcinogen, appeared in a large proportion of the corn crop for the first time in many years due to the extremely dry weather conditions in 1988. The principles discussed in this section are very germane to the ability to test for aflatoxin.

Aflatoxin is a secondary metabolite produced by the fungus, aspergillus flavus, which infects the corn during field growth. Environmental conditions that favor the production of the mold are high temperatures coupled with dry, drought type conditions during kernel maturation. Aflatoxins are particularly important metabolites because they are toxic and potent animal carcinogens in excess of certain threshold levels.

It is not uncommon for some of the corn crop in the South and Southeast to be infected with aflatoxin at levels that exceed FDA guidelines. Due to the stress this year's crop underwent, the incidence of aflatoxin extended well beyond these regions into the corn belt, especially the Eastern corn belt.

At the present time, testing technologies are not adequate. The rapid test used at the country elevator or terminal is not always reliable. And the more reliable tests are not conducive to elevator environments. The most common and rapid test is examination of corn under an ultra-violet light. This is a screening method which does not quantitate the aflatoxin. Contaminated corn will have spots on the kernel that fluoresce a bright greenish-yellow (BGY). But the presence of BGY does not necessarily mean aflatoxin is present. The possibility therefore exists of false positive test results.

Corn can also be tested with the Holaday-Velasco minicolumn or thin-layer chromatography methods. The minicolumn test, which takes about 45 minutes, gives indications of whether the corn exceeds the 20 parts per billion guideline established by FDA. Thin-layer chromatography, which takes between 3 and 4 hours, provides quantitative results of aflatoxin levels.

The minicolumn and thin-layer chromatography tests are most suited to laboratory environments. Both use chemicals that must be controlled and are not suited to the normal grain elevator environment. Recently, several new technologies, such as methods based on enzyme immunoassay or rocket immune assay techniques, have been developed to detect aflatoxin that require less chemicals and are more suited for use in grain elevators. They also produce results in a more timely manner. These technologies are currently being reviewed by the American Association of Cereal Chemists. As with any method, adequate sampling must be used because aflatoxin is not uniformly distributed among kernels.

from differences in electrical properties of grain samples, not from the meter's precision. When examining the variability of any test made with an instrument, it is essential to know the relative contribution of instrument error.

Sampling

Grain samples are obtained with either on-line or stationary methods. On-line sampling can be done manually, using an Ellis cup or a pelican sampler, or mechanically, using a diverter-type mechanical (D/T) sampler. This equipment allows samples to be drawn from a moving stream of grain being carried on a belt or within a spout, or from a free-falling stream. Samples drawn on-line are generally considered to be most representative since the grain is sampled more frequently and is more homogeneous in nature than stationary grain.

Export cargoes must be sampled with a D/T. Many barge and railcar shipments are also sampled with this method even though there is no requirement to do so. D/Ts provide quite large samples that must be reduced in a secondary sampler to more workable sizes. The smaller samples are further divided in a laboratory divider to the prescribed test portion sizes. It is important to recognize that every subdivision as well as the initial sample collection contributes potential errors. Shippers must therefore allow for sampling variations as well as established testing procedure errors when loading grain of a desired quality.

Stationary sampling is usually performed with a grain probe. Because a probe obtains samples from only one point in the grain mass at a time, multiple probings are crucial in obtaining representative samples. Probing patterns have been developed to ensure representative samples are obtained and to counteract the segregation of fine material in grain at rest in a carrier. However, probes cannot reach the bottom of barges or hopper railcars, which affect the representativeness of the entire grain mass.

Probing grain is time-consuming and labor-intensive, and current probing patterns only obtain about 5 pounds of grain. Mechanical truck probes have been developed and are being used in some locations to reduce the cost and labor requirements. But, in many locations, such as country elevators, only one or two probings per truckload are taken or a pan full of grain is taken as the truck is unloaded. This compares to the five-to-nine probings required under FGIS procedures. Limited sampling makes the test results more vulnerable to nonuniformity within the grain mass.

As indicated, the sample size used has a direct bearing on the test result's accuracy. For aflatoxin, the 10 pounds required to accurately

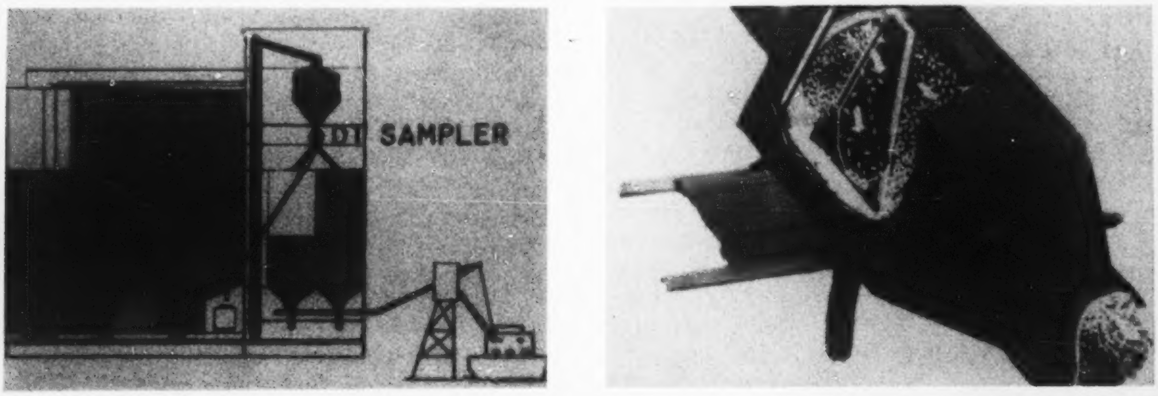


Photo credit: U.S. Department of Agriculture

The diverter-type mechanical (D/T) sampler allows grain to be drawn from a moving stream. Samples drawn from a D/T sampler are considered to be most representative since grain is sampled more frequently and is more homogeneous than stationary grain.

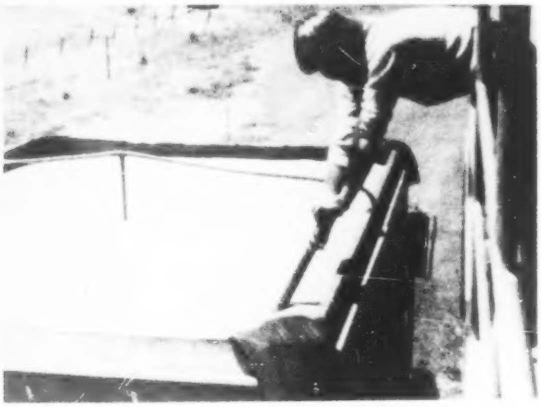


Photo credit: OTA Staff Photo

Stationary sampling is performed by a grain probe. Multiple probings are crucial in obtaining a representative sample. In many locations, such as country elevators, only one or two probes are taken compared to the five to nine probes required under FGIS procedures.

detect aflatoxin requires that a truck be sampled twice using the current five-to-nine probing pattern, which only yields 5 pounds. Getting 10 pounds from a D/T sampler is simpler since large quantities are obtained through the normal course of sampling. If increased accuracy is required, or as additional tests are adopted requiring larger sample sizes, the impact on the test's accuracy must be weighed against the cost of obtaining the sample. This will be especially relevant to samples obtained at the first point of sale from trucks.

Criteria for New Technologies

As additional tests on an ongoing basis become more relevant, criteria must be established to govern the design of rapid test requirements. Yet, development of rapid tests must meet the basic criteria associated with standardization, traceability to standard reference methods, and calibration. In addition, rapid tests must be evaluated in terms of speed, cost, accuracy, durability, and capability of handling wide ranges in quality.

The most notable advance in rapid objective testing technology has come from using NIRs to measure protein content in wheat. This technology has been discussed to some degree throughout this section. Considerable work is being done to develop additional tests with NIR, which will be particularly important at the first point of sale. Calibrations for barley protein are being developed. Work is also being done on developing calibrations for determining soybean oil and protein along with corn protein. The ability of NIR to determine wheat hardness, along with other important tests for wheat, is also being investigated.

The first point of sale will probably be the most difficult place to introduce new technologies. The time constraints are severe and the resources, both human and capital, are limited. Yet, the demands of testing at this point should be paramount in designing new tests. As these are developed and introduced, the impact of the amount of sample required to perform not only the particular test but more importantly all the tests required at the first point of sale must be evaluated in terms of practicality.

Many of the potential new tests require the grain be ground or processed before testing, while the tests currently in the grain standards are performed on the grain as a whole. As more tests are introduced that require processing, the impact of the sample size required to provide accurate results versus the quantity of sample obtained through stationary sampling becomes critical. For example, FGIS introduced a test for sunflower seed oil content. The sample size required to predict oil content accurately was determined to be 250 grams, which would have required double probing of stationary grain lots and consequently increased testing time and costs. Thus a trade-off between accuracy and cost became necessary. To overcome this problem, a smaller sample size (45 to 50 grams) was established but duplicate tests were required to help minimize the impact of lowered accuracy due to smaller sample size.

Establishing Grain Standards

Standards are established by FGIS under the authority of Section 4 of USGSA. In the case of corn and wheat, the factors contained in the standards were selected in the early 1900s. Soybean standards were established in 1922 as voluntary and brought under the USGSA by congressional amendment in 1941. No changes were made in the number of factors included until moisture was removed as a factor from wheat in 1934 and from corn and soybeans in 1985. The grade limits and factor definitions have been changed frequently during the years, however; tables 8-1, 8-2, and 8-3 contain the current standards for wheat, corn, and soybeans.

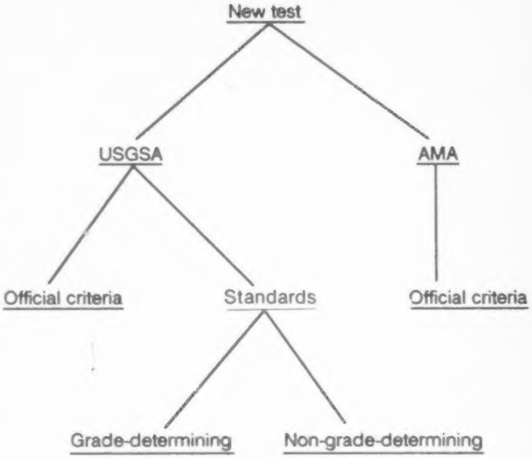
The procedure for changing grades is clearly specified in USGSA. Proposed changes require publication in the Federal Register, solicitation of comments, and, in the case of the new or amended policies, a 1-year waiting period before becoming effective.

Introducing new factors requires an understanding of the alternatives available to FGIS for implementing a new test or quality factor. The agency operates under two authorities—USGSA and the Agricultural Marketing Act (AMA)—and new tests can be implemented under either one (figure 8-1).

Three methods for implementing tests are available under USGSA. The category "official criteria" is used for tests provided only at the request of buyer or seller. Factors contained in the category of "standards" must be determined for each inspection. However, non-grade-determining factors are always reported but have no maximum or minimum associated with assigning a numerical grade, whereas grade-determining factors establish a numerical grade according to the lowest factor approach. Examples of current tests are given in table 8-4.

The Food and Drug Administration also has responsibility for grain quality issues as they relate to health and safety. Under the Federal Food, Drug and Cosmetic Act (FDCA), grain is deemed to be adulterated if it bears or contains an added or a naturally occurring poisonous or deleterious substance that may render it injurious to health. Aflatoxin-contaminated corn is one example. It was an FDA ruling that the addition of water to grain to increase its weight or value was adulteration and subject to prosecution. FDA also regulates color additives mixed with grain for identification purposes and the adhesives and coatings that may come in contact with grain transported in railcars and barges.

Figure 8-1.—Alternative Authorities to FGIS for Implementing New Tests



SOURCE: Office of Technology Assessment, 1988

The FDCA prohibits food products containing whole insects, insect parts, and excreta. Fumigation or treatment of grains already infested does not make grain legal under the act. Chemical treatment may be used as a preventive to keep grain from becoming infested, but residues from these chemicals must not exceed permissible tolerance levels. Grain is illegal if it contains residues of pesticides not authorized or in excess of safe tolerances set by the Environmental Protection Agency and enforced by FDA.

The separation of responsibilities between FGIS, FDA, and other government agencies is somewhat vague in principle. For example, grain dust is a health and safety issue covered

Table 8-1.—Wheat Standards

	Minimum limits of—		Maximum limits of—						
	Test weight per bushel		Damaged kernels					Wheat or other classes[d]	
Grade	Hard Red Spring wheat or White Club wheat[a] (pounds)	All other classes and subclasses (pounds)	Heat-damaged kernels (percent)	Total[b] (percent)	Foreign material (percent)	Shrunken and broken kernels (percent)	Defects[c] (percent)	Contrasting classes (percent)	Total[e] (percent)
U.S. No. 1	58.0	60.0	0.2	2.0	0.5	3.0	3.0	1.0	3.0
U.S. No. 2	57.0	58.0	0.2	4.0	1.0	5.0	5.0	2.0	5.0
U.S. No. 3	55.0	56.0	0.5	7.0	2.0	8.0	8.0	3.0	10.0
U.S. No. 4	53.0	54.0	1.0	10.0	3.0	12.0	12.0	10.0	10.0
U.S. No. 5	50.0	51.0	3.0	15.0	5.0	20.0	20.0	10.0	10.0

U.S. Sample grade:

U.S. Sample grade is wheat that:

a. Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or
b. Contains 32 or more insect-damaged kernels per 100 grams of wheat; or
c. Contains 8 or more stones or any number of stones which have an aggregate weight in excess of 0.2 percent of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 2 or more castor beans (*Ricinus communis* L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 2 or more rodent pellets, bird droppings, or equivalent quantity of other animal filth per 1,000 grams of wheat; or
d. Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor); or
e. Is heating or otherwise of distinctly low quality.

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[a] These requirements also apply when Hard Red Spring or White Club wheat predominate in a sample of Mixed wheat.

[b] Includes heat-damaged kernels.

[c] Defects include damaged kernels (total), foreign material, and shrunken and broken kernels. The sum of these three factors may not exceed the limit for defects for each numerical grade.

[d] Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.

[e] Includes contrasting classes.

SOURCE: Federal Grain Inspection Service, U.S. Department of Agriculture, 1988.

Table 8-2.—Corn Standards

Grade	Minimum test weight per bushel (pounds)	Maximum limits of— Damaged kernels: Heat-damaged kernels (percent)	Damaged kernels: Total (percent)	Broken corn and foreign material (percent)
U.S. No. 1	56.0	0.1	3.0	2.0
U.S. No. 2	54.0	0.2	5.0	3.0
U.S. No. 3	52.0	0.5	7.0	4.0
U.S. No. 4	49.0	1.0	10.0	5.0
U.S. No. 5	46.0	3.0	15.0	7.0

U.S. Sample grade:

U.S. Sample grade is corn that:

a. Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

b. Contains 8 or more stones which have an aggregate weight in excess of 0.20 percent of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 2 or more castor beans (*Ricinus communis* L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 8 or more cockleburs (*Xanthium* spp.) or similar seeds singly or in combination, or animal filth in excess of 0.20 percent in 1,000 grams; or

c. Has a musty, sour, or commercially objectionable foreign odor; or

d. Is heating or otherwise of distinctly low quality.

SOURCE: Federal Grain Inspection Service, U.S. Department of Agriculture, 1988.

Table 8-3.—Soybean Standards

Grade	Minimum test weight per bushel (pounds)	Maximum limits of— Damaged kernels: Heat damaged (percent)	Damaged kernels: Total (percent)	Foreign material (percent)	Splits (percent)	Soybeans of other colors (percent)
U.S. No. 1	56.0	0.2	2.0	1.0	10.0	1.0
U.S. No. 2	54.0	0.5	3.0	2.0	20.0	2.0
U.S. No. 3[a]	52.0	1.0	5.0	3.0	30.0	5.0
U.S. No. 4[b]	49.0	3.0	8.0	5.0	40.0	10.0

U.S. Sample grade:

U.S. Sample grade is soybeans that:

a. Do not meet the requirements for U.S. No. 1, 2, 3, 4; or

b. Contain 8 or more stones which have an aggregate weight in excess of 0.2 percent of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 2 or more castor beans (*Ricinus communis* L.) 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s) 10 or more rodent pellets, bird droppings, or equivalent quantity of other animal filth per 1,000 grams of soybeans; or

c. Have a musty, sour, or commercially objectionable foreign odor (except garlic odor); or

d. Are heating or otherwise of distinctly low quality.

[a] Soybeans that are purple mottled or stained are graded not higher than U.S. No. 3.

[b] Soybeans that are materially weathered are graded not higher than U.S. No. 4.

SOURCE: Federal Grain Inspection Service, U.S. Department of Agriculture, 1988.

Table 8-4.—Examples of Quality Measures Under USGSA and AMA

Authority	Example factors
USGSA:	
Grade-determining standards	Foreign material Damage Test weight
Non-grade standards	Moisture
Official criteria	Protein in wheat
AMA:	
Official criteria	Aflatoxin Falling number Pesticide residue (EDB)

SOURCE: Office of Technology Assessment, 1989.

by the Occupational Safety and Health Administration (OSHA) but prohibiting its reintroduction into grain falls to FGIS. A Memorandum of Understanding between FGIS and FDA has enabled the two agencies to work together in several areas. FDA has established action limits for many factors, such as aflatoxin in corn and pesticide residues in grain. The agreement between agencies requires that FGIS report to FDA whenever inspection results for the items identified in the agreement exceed FDA's limits.

EVALUATION OF GRAIN STANDARDS

Recent debates over grain standards, foreign buyers' complaints, and the numerous proposals for regulatory and legislative changes echo earlier calls for change. Recent complaints concerning certificate final contracts, excess foreign material at destination, spoilage, and heating during transit are nearly identical to those of the late 1800s. (Certificate final in the export/import contract means that grade is determined at the point of loading and the buyer has no legal recourse regardless of delivered quality, unless it can be proved the origin grade was incorrect at the time of loading.)

These problems have been documented repeatedly in congressional hearings in 1908, 1928, 1975, and 1986 (3). Even the wording is almost identical, despite a span of some 75 years. The Senate Report 988, of July 27, 1912, criticized the current system for rewarding adulteration:

> Under the present conditions an enormous system of mixing or adulteration of grain is forced on all the home markets and also the foreign market, destroying all confidence in our grades and working to the detriment of the grain trade.

In 1986, Representative Byron Dorgan (D-ND) used similar phrases:

> In short, the U.S. system being what it is allows and encourages dockage to be added back into wheat shipments . . . unless we confront this problem, we will further erode our export potential.

Historical Review

The legislation establishing Federal grain standards was passed in 1916 following more than 50 years of debate and repeated attempts by the grain industry, trade associations, and boards of trade to establish private and regional measures of grain quality. Private firms can increase profits by individually differentiating quality from that of other firms. As noted earlier, this self-interest blocked every attempt at obtaining voluntary adoption of uniform standards even though the trade associations recognized that the industry as a whole would benefit.

After many years of educational efforts and attempts to obtain support, the National Grain and Feed Dealers Association agreed to endorse a compromise bill for Federal standards. The compromise garnered reluctant support from the two opposing positions of voluntary adoption of inspection and grain standards versus full Federal control. The compromise allowed Federal supervision of uniform standards and inspection by private firms, many of which were already in business in 1916.

More than 150 bills and amendments have been submitted to Congress since Senator Paddock first proposed Federal legislation in 1890 to establish measures of quality that would be uniformly and objectively applied. Yet the basic premises and procedures of the Grain Standards Act of 1916 remained intact until 1986. Further, the complaints and persistent problems regarding quality have continued for over a century despite all the legislative, administrative, academic, and industry efforts spent on improving quality measurement. Several obstacles to a permanent solution must be recognized and dealt with if current efforts of Congress and industry are to succeed:

- The changing nature of the industry in terms of technology and genetics results in quality characteristics that change from one crop year to the next and from one part of the country to the next. All these diverse qualities enter the marketing channels and must be handled.
- Industry and government have often refused to accept that problems exist. Faith in the infallibility of a market system has made it difficult to accept that government agencies have a function in setting uniform grain standards in order to facilitate an efficient market.
- Most of the participants in the debate have seen themselves as adversaries since the beginning of the discussions. Each group—farmers, processors, grain merchandisers,

and government—has expended considerable public effort trying to blame one or more of the other groups.

- The USGSA and the regulatory agencies implementing the act have focused on one objective—"to facilitate marketing." Economic principles have not been incorporated into the grade factors, factor limits, or the many seemingly arbitrary changes.

Objectives of Grain Standards

Since the beginning of Federal regulation in 1916, the official purpose has been to provide uniform standards for promoting and protecting grain moving in interstate and foreign commerce "so that grain can be marketed in an orderly and timely manner and that trading in grain may be facilitated." It has seldom been recognized that the lack of an economic justification in that directive has caused much of the difficulty in arriving at a consensus on grain standards and standardization within the grain industry. Although early researchers frequently referred to "intrinsic value" and "value in end use," these criteria were seldom in evidence when developing standards, or in the numerous changes that were introduced in subsequent years.

Much of the disagreement over specific changes is the result of explicit or implicit disagreement over the objectives of standards. Each group held a different view. Many in industry and government viewed standards as a convenience for merchandisers. Processors wanted the standards to indicate yield of processed products. Farmers wanted assurance that discounts associated with grade factors were based on differences in real value in use. Congress often viewed the standards as a cause of foreign complaints and lost export markets. Clearly, if grain exporters, grain processors, Congress, and farmers hold divergent views on what grain standards are intended to accomplish, they cannot be expected to agree on which grade factors would meet their diverse and conflicting purposes.

The lack of clear goals, objectives, and criteria inevitably led to reversals as well as arbitrary inconsistencies. For example, test weight limits in corn for grades No. 1 and No. 2 were in the original standards in 1916; were added to grade Nos. 3, 4, and 5 in 1918; were lowered in 1934; and were raised in 1959. Throughout all these changes, researchers questioned whether test weight was a relevant measure of value in any grade. Those who argue that the only objectives of standards is to describe physical and biological characteristics have been unable to find a criterion by which they could justify the characteristics chosen. For example, why measure kernel density but not kernel size? Why measure the percent of split and broken beans but not the percent of whole kernels in corn? Grain has many physical and biological properties, and without additional criteria for guidance, the factors and factor limits become arbitrary numbers.

In practice, few markets quote prices for No. 1, 2, and 3 corn, soybeans, or wheat. In nearly all cases, a base price is given for one grade and discounts or premiums attached to deviations on each factor from that base. At the country elevator level, for example, nearly all corn is purchased on a No. 2 base and farmers' prices are established by discounting each factor that falls outside of the No. 2 limits. International markets generally specify No. 2 soybeans or No. 3 corn, and prices in the contract are usually quoted for that one grade with adjustments for deviations.

A set of clearly stated objectives for standards based on sound economic principles was absent in legislative and administrative changes between 1916 and 1986. The many changes during that period did little to resolve the basic problems and issues. In 1986 a relatively simple change in the language of the USGSA opened the door to a new era in the identification of quality as a means of efficient communication of information about value.

In June 1986, the North American Export Grain Association submitted a report emanating from a series of industrywide workshops. This report, entitled "Commitment to Quality," presented a consensus to serve as guidelines for Congress and FGIS in revising standards

(6). One of its most important aspects was a new definition for the objectives of grain standards. The four objectives were identified as:

1. to define uniform and accepted descriptive terms to facilitate trade,
2. to provide information to aid in determining grain storability,
3. to offer end-users the best possible information from which to determine end product yield and quality, and
4. to create the tools for the market to establish incentives for quality improvement.

These objectives were incorporated in the 1986 Grain Quality Improvement Act with the passage of Public Law 99-641 on November 10, 1986. FGIS for the first time had a set of criteria on which to base changes in standards and to evaluate the numerous proposals for change. Each criterion provides a basis for assessing current standards and the recent efforts by FGIS to improve measurements of quality.

Facilitating Trade

Almost any set of factors can meet this criteria. It is important that grain be grouped into a relatively few number of categories to make buying, selling, and classification efficient and inexpensive. Trade is facilitated by having a small number of grades determined by a minimum number of factors. From the standpoint of trading simplicity, three numerical grades in the corn standards may in fact be more desirable than five.

The factors in the current grades are for the most part easily measured and provide a basis on which buyers and sellers can communicate price and appropriate discounts. Some have the additional advantage of being commonly used in international trade and thereby serve to facilitate communication within the international as well as domestic market.

Since almost any set of factors and grade limits can be handled equally well by the grain industry as long as they are universally accepted, recent FGIS changes have made little improvement on this criterion.

The technology and terminology for measuring current factors have been in use for enough time to make the trading of grain on these factors and grades limits extremely efficient. Domestic and international contracts have been written using this terminology for many years. Trading in the marketplace is readily handled with a minimum of specification. These terms are adequate for basic contracts and quotes in the futures market as well as in international trade. Basing price on the numerical grade, millions of bushels change ownership with a simple phone call.

Aid in Determining Grain Storability

The factors that influence storability of grain have been well documented by many scientists, dating as far back as the grain storage studies done in the early 1900s by Dr. Duvel of USDA. These factors are moisture, temperature, air flow, mold, and insect infestation. The more technical attributes of these characteristics are covered elsewhere in this assessment. The length of time grain has been held in storage and the condition under which it has been stored are also important criteria.

Current tests for factors contained in standards provide little information on direct measures of storability. Moisture content is provided in terms of averages, but it has been demonstrated that the range of moisture among individual kernels may be more important than the average. The standards identify damage, but this is an arbitrary determination of a stage of development and storage deterioration that does not provide information on how much longer the grain may be stored before it goes out of condition. Numerical grades alone certainly provide no information on storability. Foreign material, test weight, damage, and moisture are thus indirect indicators at best even though they are reported on every inspection certificate.

Changes in inspection practices and standards have done little to improve measurement of storability since the 1920s, when Dr. Duvel suggested acidity as a measure of storage life and an indication of mixtures of old and new crop grain. The 1986 changes in the interpretive line slides used to identify damage in soybeans did not improve the ability of the standards to predict storability. However, the correlation between damaged kernels and levels of free fatty acid better equipped standards to indicate oil quality.

Most current measures for storage life are based on laboratory procedures. No rapid commercial test is available to provide a quick indication of the stage of deterioration or the time remaining before grain's condition worsens.

Measuring Value in Processing Products

Because most grains are used for more than one purpose, it is not a simple matter to identify the characteristics that influence value (see ch. 4). The nutritional composition, starch content, and recovery rate of corn and baking characteristics of wheat are all end-use properties desired by processors. Few of these, however, can be converted directly to measures of physical or intrinsic properties of the raw grain. Research in recent years has identified some factors that relate to value that can be measured in the commercial market channel. For example, hard endosperm corn provides a higher yield of flaking grits. Obviously, high oil and high protein soybeans provide higher yields of oil and soybean meal. Breakage susceptibility tests identify the ability of corn to withstand handling without increasing breakage. Many tests—such as falling number, farinograph, hardness, and baking tests—are available that indicate baking and milling characteristics of wheat and are frequently used in laboratories in the United States and Europe. But the industry does not completely agree that these attributes always clearly indicate value.

Factors currently contained in the standards do a poor job of meeting the criterion of end-use value. Soybean standards include little indication concerning oil and protein content. New varieties of wheat have diminished the effectiveness of class and grade for evaluating flour and baking characteristics. Information from corn standard factors is often unrelated to its feeding value or starch yield. In general, those characteristics of raw grain most closely associated with value of products derived are not currently covered by the standards. Purity and cleanliness in terms of foreign material, numbers of insects, or other grains provide one of the few indications of value in the current standards. Even here, however, there is lack of clarity; the term "foreign material" means different things in each grain, and the term "broken corn and foreign material" (BCFM) does not differentiate between broken corn and foreign material despite the difference in value.

FGIS in the last few years has moved toward improving the measurement of end-use value. For example, even the simple step of rounding dockage percentage to the nearest one-tenth in wheat gives a better indication of the amount of grain versus nongrain being purchased. Compared with the previous method of rounding down to the nearest half-percent, the new approach better reflects true value. FGIS has also taken steps to differentiate more critically on damage in soybeans. The change in the interpretive line slides has been linked to the level of free fatty acid, which is in turn a direct measure of the quality of oil derived from the soybeans. Progress is therefore being made toward finding better measures of value.

Additional measures are available that have not been incorporated in the standards. There is a lack of total industry agreement that these measures are sufficiently accurate and reliable to be introduced. Continued commercialization of measures of breakage susceptibility in corn and soybeans; intrinsic properties of corn, soybeans, and wheat; new measures of baking properties and classification of wheat varieties; and rapid measures of oil and protein in soybeans are all candidates for inclusion in the standards or should at least be made available as information.

Providing Market Incentives

Measurement of factors that result in price differentials in the market provide an incentive for each point in the market channel to make decisions to improve quality and avoid discounts. This incentive works back through the market channel to producers, who may change harvesting, drying, and storing practices (see ch. 7) or may select different varieties (see ch. 6). Preference for varieties with certain quality characteristics will be conveyed to plant breeders who will in turn generate better varieties. In a competitive market, profit is a strong driving force in any company's decisions, whether they be exporters, individual elevator managers, producers, or plant breeders. While the market itself sets incentives in terms of prices and price differentials, the standards are not neutral in this scenario. For example, farmers have an incentive to select corn varieties that weigh at least 54 pounds per bushel in order to avoid discounts in the market. This producer incentive translates into incentives for plant breeders, who have spent significant research funds to develop varieties that will produce a high test-weight corn under normal conditions.

Current grain standards provide incentives in several ways. For example, the allowance of 3-percent BCFM in No. 2 corn, in conjunction with the market practice of paying top price for No. 2 corn, gives farmers an incentive to incorporate 3 percent BCFM in their deliveries. By the same token, elevator managers have an incentive to clean or blend in such a way as to deliver 3 percent BCFM throughout the market channel. Any shipment containing less than 3 percent BCFM is a lost profit opportunity. Shipments containing more than 3 percent BCFM will usually receive a discount. The step functions between the grades create incentives for blending when grain is purchased on grade alone. The wider the range between grades, the greater the number of factors, and the greater the number of grades, the greater is the opportunity for blending when purchasing on grade without specifying factor limits.

The other side of this coin is the lack of incentive for improving quality on those characteristics omitted from the standards. With no price differential for soybeans with high oil and protein, farmers have no incentive to select varieties that will represent greater value to the processor. Yield becomes the primary and in most cases the only criterion on which to select the variety to be planted. A second example is the drying temperature of corn. Although most corn processors object to the use of high temperatures during drying, the market does not differentiate between corn dried at high and low temperatures. The premiums paid by a few dry millers for low-temperature-dried corn indicate that farmers do respond to these incentives when offered. At present the incentives are not offered by means of the standards, but by means of contracts in localized areas. It is especially difficult for buyers some distance from the production point to obtain qualities they desire when those qualities are not incorporated in uniform standards and terminology.

Recent FGIS efforts have had limited effect upon incentives within the market channel. The removal of moisture as a grading factor reduced the number of factors on which blending was required when purchasing on grade only, but the market still generates income from blending wet and dry corn. The change in rounding procedures for dockage percentages in wheat removed the incentive to blend dockage just below the next higher break point. However, the number of grades and the steps between grades have not been significantly altered, and incentives and disincentives still fall short of the ideal.

Measurement and sampling technology or testing is a problem in terms of incentives only so far as the accuracy of the equipment will not accommodate a finer distinction between qualities on certain characteristics. Increased accuracy will permit narrowing the spread between numerical grades, thereby reducing the incentives for blending when purchasing on grade only.

Integrating the Four Objectives

Changes in grade-determining factors, or factor limits, should meet the four objectives of grain standards. But, not all alternatives will contribute to all four objectives, and it is likely that conflict between the objectives will develop. For example, complex and lengthy tests for measuring end-use value will slow the inspection process, increase marketing costs, and thereby detract from the purpose "to facilitate trade." Similarly, incentives are best created by a continuous discount schedule on each factor, starting from zero. But a zero base requires each buyer to specify factor levels in the contract. Numerous contract specifications increase the number of segregated lots and reduces the interchangeability of shipments. Increasing the amount of information available to users increases the difficulty of merchandising uniform lots.

The "perfect standard" that optimizes all four objectives may not exist. The final solution will be a compromise among some of the objectives (e.g., sacrificing complete information for all users in order to facilitate orderly efficient marketing) and among various buyers and sellers.

Alternatives to the Present System

An evaluation of the alternatives to the current system in the United States illustrates some of the trade-offs inevitable in establishing grain standards. The system today is generally known as "numerical grades determined by the lowest factor."

The "lowest factor" approach requires that the grade be set by the factor representing the lowest quality. For example, if the test weight of corn is 53 pounds per bushel, that sample is graded No. 3 even though all other factors are equal to No. 2 or better. This method has the advantage of simplicity and is used by many of the major grain-exporting countries. However, it does not always reflect true value since it fails to consider factors above the minimum. Considerable variation in quality can occur between shipments without a grade change. The lowest factor system also encourages blending to bring all factors down to the quality of the lowest factor determining the grade, and therefore does not generate incentives for quality improvement unless limits are established by contract that are more restrictive than the grade limit.

In export trade, most contracts specify that the grade determined at origin is the legal basis for any dispute or arbitration regarding quality. This certificate final system, which was in use prior to the USGSA, provides advantages in terms of efficiency and costs. Other alternatives are currently used in other countries (see ch. 10 and companion report) and variations of the official U.S. system are being used even in the domestic market. Understanding the basics of each alternative can help develop policy for directing future quality regulations.

Total Defects

Under the lowest factor approach, all factors can be at the maximum limit for the determination of a particular grade. For example, No. 2 corn can have 54 pounds test weight, 3 percent BCFM, 4 percent damage, and 0.2 percent heat damage. This provides the opportunity to blend on one or more factors to achieve the maximum allowable limit within that grade. A system of "total defects" introduces one more limiting factor that sums the defects in that grade across all factors and places a maximum that would be more restrictive. Thus the accumulated value of the defects would become more restrictive than the individual factors. In the example just given, the defects are BCFM, total damage, and heat damage. Under the total defects system, a maximum value of 6 percent might be established, for example, and the corn would be considered No. 3 if the sum of damage, heat damage, and BCFM exceeded 6 percent. Currently, the wheat standard includes a total defects factor with a maximum limit of 3 percent for No. 1. If shrunken and broken kernels, for instance, are at the maximum No. 1 limit, which is 3 percent, all other defects would have to be at 0. This approach provides additional information about quality and an incentive to increase quality if the total defects figure is more restrictive.

The total defects approach differs from the lowest factor only by accumulating the sum of individual factor results. The greater restriction it entails could also be achieved by changing limits on the present grade factors. Total defects also contains a logical inconsistency: It establishes limits on three factors for No. 2 wheat but if the sample meets all these criteria, it will be classed as No. 4 on the basis of total defects.

Absence of Imperfections

The "total perfect kernels" approach also sums the percent of defects, but subtracts the total from 100 to obtain the percent of perfect kernels. Each grade has a minimum limit on percent of perfect kernels. Corn grades in China are based on this system, and U.S. standards for oats include a factor for "sound oats." This system differs little from the "total defects" concept except that it reports absence rather than presence of defects.

Weighted Factor

The "weighted factor" approach would include a set of grade-determining factors and factor limits, but each factor would exert a different effect in terms of grade determination. This is in contrast to the lowest factor approach, in which the grade is lowered when any one factor result exceeds the limit. Instead, defects would be divided into major and minor categories and each assigned a weight to be multiplied times the percent of that defect present. The sum of the defects times the weighting factor would determine the grade. Grade would be influenced by the number of factors below grade, the distance each of those factors fell below the grade limit, and the relative seriousness of the defect.

This system would incorporate more information in the numerical grade and allow finer distinction among the combinations of factors. Its disadvantage is its complexity, the arbitrariness of the weighting factor assigned to each defect, and the lack of clear criteria on which to set the break points between grades. In order for the numerical grade to indicate end-use value, the weighting factors would have to differ among uses. The complexity of such a system would probably eliminate this alternative on the criteria of the first objective of standards—"to facilitate trade."

Contract Specifications

The issue of whether standards are required or whether each buyer may simply specify terms in their contract has been debated since the idea of numerical grades was first presented to merchandisers in the late 1800s. So long as contracts are legally enforced, buyers and sellers may agree to any set of factors, characteristics, and conditions of shipment they desire. The advantage of numerical grades over contract specifications is that they facilitate communication. When the grain trade became too large for buyers and sellers to physically and simultaneously view the grain being sold, terminology was required that would permit description by factors. The numerical grade was chosen as a way of describing several factors in one number. Each buyer could identify the characteristics and factor limits that best meet the conditions in a particular plant. If the buyer's needs are unique, however, resale in the market becomes difficult and segregation is required for each one's specifications. The efficiency of the current marketing system relies heavily on uniformity for the majority of the crop being marketed.

Although most foreign buyers now use numerical grades for purchasing corn, soybeans, and wheat, they almost always include additional factors besides the numerical grade in their contracts. Numerical grade alone seldom conveys sufficient information to satisfy a buyer's needs. Other factors are therefore specified. It is a small step to go to an entire factor basis system and eliminate numerical grades. The primary disadvantages are a much wider range of quality characteristics between vessels and thus difficulty in resale if other buyers do not want the same specifications, greater difficulty in segregation and blending to a wider range of specifications, and increased complexity in writing contracts.

None of these disadvantages is insurmountable. The problem of reselling uniform lots has become much less important in recent years.

The number of times a vessel is resold after leaving port has fallen compared to the 1970s scenario. The complexity of identification is also less daunting since most buyers are already specifying grade plus two or three factors; they would be specifying only one or two more. There would be greater problems in keeping qualities segregated throughout the market channel if there were no numerical grades.

One of the purposes of blending is to achieve a uniform product, and the first objective of standards is to facilitate merchandising. This purpose is not accommodated by a system where all buyers develop their own set of quality factors, their own definitions, and their own limits. The complexity and inefficiencies of such a market would result in a major reduction in welfare for both buyers and sellers throughout the market chain. Numerical grades therefore are a means of creating uniformity of quality in the market channel. They are most useful if they reflect the needs of the majority of buyers in the market so that additional contract quality specifications are the exception rather than rule.

Fair Average Quality

The contract for fair average quality (FAQ) specifies that the grain shall be equal to the average quality of grain exported or imported at a specific location. The most common FAQ contract in previous years has been the GAFTA (Grain and Feed Trade Association) of London, which specifies that quality delivered will be equal to the average of the quality from the country of export to the importing country for the month in which the delivery was made. Samples are taken from each vessel and stored by GAFTA in their London laboratories. A composite sample at the end of each month is created as the standard, and shippers who think that the quality of their shipments did not meet FAQ submit samples to be judged against the GAFTA standard. Arbitration decisions are based primarily on visual inspection by an arbitration committee. Most GAFTA FAQ contracts are based on delivered quality. The standard varies between months, countries of origin, and crop years. The quality characteristics are few in number and consist primarily of visual observation.

The advantage of FAQ is its simplicity and its flexibility for adapting to changing crop years. This advantage to the seller is, of course, a disadvantage to the buyer. The contract does not cover all factors on which buyers might like information, and the floating standard leaves the buyer uncertain as to what quality may be received for processing. It is often a destination contract (advantage to buyers, disadvantage to sellers) and covers factors not likely to change in transit. Since half the vessels are mathematically below the FAQ standard, it is conceivable that many contracts would require court arbitration. In fact, the system is manageable because FAQ factors and sampling methods are not sufficiently specific to support arbitration action except in cases of extreme deviation from the standard.

The FAQ system provides no incentive for improving quality since it only describes whatever quality is produced. The extent to which the FAQ system describes value to users depends on the factors included. In the case of the GAFTA corn contracts, the factors describe primarily condition of the grain rather than intrinsic value characteristics. Some of the soybean contracts include oil and protein. The simplicity of FAQ facilitates trade but the potential for disputes and arbitration can reduce marketing efficiency.

Variations on the FAQ system include contracts that specify origin instead of destination. Canada and Australia have sometimes generated a fair average quality based on harvested quality for that crop. The FAQ standard is usually established with respect to selected characteristics of special importance.

In recent years the FAQ contract has been less frequently used. Argentina, South Africa, and Brazil all report exporting primarily on numerical grades. However, European buyers have reported continued use of destination FAQ on soybeans.

Destination Grades v. Certificate Final

Most contracts originating in the United States specify that grade is final at origin. This means that the grade certificate, issued immediately after the vessel is loaded, is the final document on quality and the buyer has no recourse beyond proving incorrect inspection on the origin samples. Foreign buyers must prove that the vessels were improperly loaded or inspected at origin before they can claim restitution for quality. Grain received in poor condition, badly broken, spoiled, sprouted, or insect-infested is not sufficient evidence on which to base claims for damage because the contract specifies origin certificate final.

Certificate final is a highly efficient marketing technique, and enables minimum cost quality guarantees up to the point where the exporter transfers responsibility for quality to the captain of the vessel or to the importer. It has the disadvantage of the ultimate customers' dissatisfaction with the delivered quality and their inability to control quality when several handlers stand between shipper and user. It also enables the shipper to load closer to the quality limits without regard to the inevitable consequences of placing that quality in the vessel.

The alternative is destination grades (often in conjunction with a cargo, insurance, and freight sale). In this case, the seller guarantees delivery to the foreign port and guarantees quality at that destination. This alternative has often been suggested as a solution to the problem of foreign complaints. But many unanswered questions remain about such contracts. For example, who will take the destination samples and how? Second, what type of guarantee can shippers make for a vessel that will be distributed among 10, 20, or even 50 different buyers, each one getting only a small portion from a vessel with a highly variable quality among holds? Third, since the buyer specifies the quality characteristics and frequently requests a moisture content unsafe for long voyages through warm water, how can shippers guarantee quality at destination?

The buyer has always had the alternative of using a contract that specifies destination quality. Few shippers are willing to take that type of risk at a price the buyer would be willing to pay. With no control over unloading or sampling, shippers are in a poor position to guarantee destination quality and the number of contracts taken into arbitration court would undoubtedly rise dramatically, resulting in a significant increase in cost and delays in settlement.

Origin and destination contracts can be used to guarantee quality under any set of standards. Yet, the two systems incorporate different incentives. Destination guarantees place additional responsibility, and thus economic incentives, on the exporter to load grain that will maintain quality during transit as well as meet the contract at time of loading. This alters the loading strategy. Under origin grades, for example, a 14.0-percent moisture contract could be met by blending 8 and 16 percent moisture corn. Under destination quality guarantees, this blending would not be a good strategy under most time and temperature conditions. The high-moisture corn would probably result in damage levels and spoilage at destination exceeding the contract limit.

The issue of origin and destination grades must also be considered in the context of domestic markets. The same issues exist as in the export market, but the results are different for two reasons:

1. the time between origin and destination is usually much shorter in the domestic market; and
2. sampling and inspection procedures at origin and destination are subject to a single set of regulations in the domestic market, whereas FGIS has no control over sampling and grading at foreign destinations.

Domestic contracts specify origin or destination grades as well as whether settlement will be based on official or private inspection results. Confidence in accuracy is developed with a large number of transactions over a period of time and by the option of calling for FGIS inspection and an appeal if needed. This confidence often results in acceptance of non-FGIS origin inspection where direct contact between buyer and seller has generated mutual trust. Trade rules and arbitration procedures established by the National Grain and Feed Association also provide an important alternative and supplement for domestic trade.

Dual Grades

A dual grading system could be based on separating domestic and foreign markets or separating use. Separate export standards have often been suggested as a way to compete in international trade with more restrictive quality specifications. The Canadian system establishes separate grade requirements for export wheat and controls purchases, movement, and cleaning procedures between country elevators and the ports to administer this system (see companion report). Separate food grades and feed grades have also been suggested for corn and wheat. Food grades would be more restrictive, especially with respect to sanitary quality factors, and could include more information on value in processing.

Separate standards for different users could provide more information on value. The food grade or export grade could have price differentials that would generate market incentives for improved quality. The market would direct the higher qualities into the higher valued uses. The dual system would create a more complex marketing system and would probably increase the cost of segregation and transport. Probably the greatest difficulty would be determining which standard and discount to apply to the producer. Since ultimate use would not be determined at the time of farmer delivery and, in fact, intended use might be changed more than once in the market channel, the higher discounts on food grade or export grade would have to be applied against the producer. This would generate incentives for quality improvement on all grain at a cost that would not be justified for feed use in domestic markets. Dual standards would thus not facilitate an efficient market.

APPLYING ECONOMIC CRITERIA TO GRAIN STANDARDS

As the four objectives of grain standards specified in the 1986 Grain Quality Improvement Act do not lead directly to a system of grades and standards, an intermediate set of guidelines is required to:

- **Define uniform and accepted descriptive terms to facilitate trade.**

  This requires a small number of categories established by clearly defined factors. The factors must be readily measured in commercial trade and objectively determined by technology that gives repeatable results at each point in the market channel. The factors must be acceptable to and used by most participants in the market. Trade is also facilitated by stability and absence of change, since any change results in uncertainty and adjustment.
- **Provide information to aid in determining grain storability.**

  This purpose would be met by tests that reflect storage history as well as predicting remaining storage life. Information on infestation by molds, fungi, and insects needs to be accompanied by the extent of the development and deterioration. Kind of infestation is also an important measure of storability as a guide to actions required to inhibit further deterioration.
- **Offer end-users the best possible information from which to determine end-product yield and quality.**

  The characteristics of raw grain that indicate the quality and quantity of processed products differ with different industries. Factors selected for inclusion in standards should either be common to several industries or be important to an industry consuming a significant portion of the crop. The more directly the factor measures the desired end product, the more efficiently will the standards reflect value.

- **Create tools for the market to establish incentives for quality improvement.**
  Incentives in standards are created in part by including factors that are economically important. To provide the market the maximum opportunity to establish price incentives the standards should: 1) minimize the distance between factor limits for each numerical grade; 2) report all values as accurately as measurement technology allows, using standard mathematical procedures for rounding to the nearest significant digit; and 3) convey important economic information to producers that will enable them to respond to producer preferences related to value.

Grade-Determining, Non-Grade-Determining, and Official Criteria Factors

The factors selected as indicators of value may be included as grade-determining factors, as non-grade-determining factors, or as official criteria. As described earlier in this chapter, grade-determining factors set numerical grade according to the factor limits established. Non-grade-determining factors contained in the standards do not influence grade but must be reported as information whenever an official inspection is made. Factors defined as official criteria are measured and reported only when requested.

Assigning each factor to one of the three categories requires a guideline that can be used objectively. As noted previously, standards should serve the needs of a majority of users and should reflect value for those uses. This suggests that grade-determining factors should be those that relate to sanitary quality, purity, and soundness (absence of imperfections). Using this guideline, the grade would be based on factors such as impurities, foreign material, total damage, and heat damage. The lower the values of any of these defects, the greater is the value of the product. Non-grade-determining factors would be those related to properties such as broken kernels, moisture, oil and protein content, and other intrinsic characteristics or physical properties that influence value for the major processing uses. Higher or lower percentages for these do not necessarily mean higher end-use value over the entire range. For example, the required level of protein in wheat depends on the ultimate product to be made from the flour. Lower moisture content means more dry matter per pound, but 5 percent moisture corn is not generally of greater value than 12 percent because of the effects of overdrying. Usually some optimum value is indicated for each of these factors, but the optimum varies with the use and location in the market channel.

Under Section 4 of the USGSA, factors contained in the standards must be measured during any official inspection. Those considered official criteria are measured upon request. Although the advisability of that particular part of the law is a matter of debate, in its present form it leads to the conclusion that characteristics most important to the largest number of users would be incorporated into the standards. Those of lesser importance, or important to only a few users, would be considered official criteria available upon request to buyers who need them. Thus moisture and basic intrinsic properties—such as protein content, kernel hardness, and falling number tests in wheat; protein and oil in soybeans; and starch in corn—might be incorporated as non-grade-determining factors. Breakage susceptibility and kernel hardness in corn and kernel size in soybeans are examples of factors to be made available under official criteria.

The advantage of putting the major factors in as non-grade-determining factors rather than official criteria is that the characteristics would move into the market channel much more readily. Obligatory measurement throughout the market would spread the cost across the entire industry. The cost per unit would be insignificant and therefore the information would be readily available as an incentive. A characteristic that must be specified by a separate request from each individual buyer would increase the cost of information. For example, the true value of information on test weight is irrelevant under the present system since everyone is required to measure test weight. The marginal cost to the buyer for that information is nearly zero. In contrast, if only one buyer specifies oil content in a soybean contract or falling number in a wheat contract, the cost of information would be much greater because the cost of measurement throughout the market channel would be borne by the single buyer and would be spread over only the bushels that buyer purchased.

Objective criterion based on the four purposes of standards has thus provided a basis for choosing factors and for dividing them among grade-determining, non-grade-determining, and official criteria.

Establishing Grade Limits

As noted earlier, the grade limit on various factors is an automatic incentive throughout the market channel to add materials or to blend to reach that limit. Blending damaged soybeans with good ones does not increase the value of the damaged soybeans, but it does increase their price, for they may now be sold as a higher grade. The criterion of providing incentives for improving quality dictates that the base be set at zero. The overall objective of a standard is "to describe the value of the lot of grain being sold." If the percent of damaged kernels can change from 5.0 to 6.9 percent without changing grade, then numerical grade alone does not provide complete information on differences in value. Current soybean standards allow 1.0 percent foreign material and no discount is applied by the market, implying that any level between 0 and 1.0 percent represents equal value. The first 0.5 percent of foreign material in a shipment of soybeans has no more real value than the third 0.5 percent, even though the third is discounted and the first is not.

Tighter limits on existing grade factor limits would reduce the incentives for blending and provide a more accurate measure of value as long as discounts continue to be applied on the same grade. However, it is as difficult to justify an arbitrary limit of 0.5 percent as it is to justify an arbitrary limit of 1.0 percent. The only objective limit is zero, with market discounts being applied for additional levels within the ability of sampling technology to differentiate.

The base for the non-grade factors is of course immaterial, since it is not grade determining, and the market is now free to choose what, if any, price adjustment is to be made for different levels of those factors.

The zero base concept is limited by the freedom of the market to respond. Unless (or until) export contracts and prices are established at zero base, merchandisers could start discounts at any level they desired, including the current factor levels for No. 2 corn and for No. 1 wheat and soybeans.

Number of Grades

The final question in setting standards is the number of different grades required. The number of numerical grades differs among grains—malting barley has three, soybeans and sorghum have four, and corn and wheat have five—and all grains have a sample grade designation. Historical records provide no rationale for these numbers and the justification for the different numbers between standards is not clear. The fewer the numerical grades, the simpler is the marketing and the less space required to segregate these grades in storage.

A single grade would force the foreign buyer to specify the quality characteristics and the level of those characteristics desired. Buyers would no longer receive 4 percent BCFM by default when ordering No. 3 corn. They would be forced to specify the levels desired and would know in advance the trade-off with price.

The market seldom uses more than two grades. More grades increase the complexity for the market and provide no increase in information. The disadvantage of a single grade is that nearly every buyer must use one grade or specify levels on each factor. This would result in increased diversity of contracts, less opportunity to resell uniform lots, and increased transaction costs. The final number of grades to be established for each grain must be a compromise between the purposes of providing incentives, identifying value, and facilitating trade.

EVALUATION OF RECENT LEGISLATION

Optimal Grade

The optimal grade concept proposed a single grade, with low values for selected defects and discounts on any defects above the base. The object was to reduce the incentive for blending built into the current standards by lowering the limits and thereby better meeting the fourth objective of standards. It used the principle of grade factors being required to reflect cleanliness, soundness, and purity. It set low levels for that grade but not at zero. It would have met the criteria of simplicity, facilitating trade, and removing incentives for blending. However, it did not meet the criterion for measuring quality for various uses. Its greatest deficiency was a failure to identify the non-grade-determining factors that would be incorporated in the standards. It also failed to eliminate completely the incentive to blend off large quantities of poor quality grain by not setting the base values at zero. Congressional rejection of the optimum grade was probably more a reflection of problems of implementation than of failure to meet the criteria established by the purposes of grades.

The Grain Quality Improvement Act of 1986

Perhaps the most important contribution of this legislation was introducing into the USGSA the four explicit objectives for grain standards, including three relating to economic value. Without these objectives, the standards had primarily reflected response to pressure from various groups. Without support from one or more major associations or organizations, it was extremely difficult to make any changes in the standards because the only criterion was that of facilitating trade. As noted, FGIS now has criteria on which to base changes and can justify those changes in terms of what is best for the industry.

Prohibitions v. Market Incentives

Developing solutions to the problems and issues raised by grain standards faces two basic choices:

1. legislative prohibitions against practices that are detrimental to quality; and
2. changes in the economic incentives of standards in pricing practices to allow the market to discipline offenders.

The first alternative focuses on controlling the process by which grain is marketed; the second, on accurately evaluating the product and value of different qualities.

Throughout history numerous bills and amendments have tried to legislate specifics in grain standards. Nearly all legislative attempts have failed. The few successful activities since the late 1800s have focused on setting policy and creating a framework for administrators to implement rather than legislating specifics. During the 1980s numerous bills or amendments have been submitted to restrict the way in which foreign material, dockage, or dust can be handled, particularly in the export markets. The 1986 Grain Quality Improvement Act included a prohibition against reintroducing dust or foreign material into the grain stream once it has been removed. The intent was clear: to improve the quality of the grain being exported and especially to improve the U.S. image in international grain markets. The success of this type of legislation is not yet clear. Yet several difficulties can be identified in implementing prohibitions while leaving intact the standard structure that generated the incentives for blending when purchasing on grade only.

The prohibition in the 1986 Grain Quality Improvement Act focuses on controlling the process rather than the product. Consequently, its enforcement has presented numerous problems, not the least of which is a definition of what constitutes foreign material, which the standards define in many different ways and identify with many different names. For example, in corn only one factor encompasses all nongrain material: BCFM, which is defined as any material passing through the 12/64-inch sieve plus noncorn material remaining on top. Wheat includes a factor for foreign material and one for shrunken and broken kernels as well as a category called dockage. Barley standards contain three factors: dockage, foreign material, and broken kernels. In nearly all cases, foreign material is defined in conjunction with particle size, meaning materials that got through a certain size sieve. The sieve size varies among grains. In almost all cases, not all foreign material is actually removed, and in almost all cases the foreign material contains small grain particles that are not "foreign" at all. (For information on problems in defining grain, see ref. 1.)

Another problem with the prohibition approach is that the quantity of foreign material or broken kernels incorporated into a grain shipment is controlled by the contract in conjunction with the grade limit. Therefore, the prohibition does not prevent leaving dirt, dust, and foreign material in the grain, nor does it prevent blending of different lots of grain containing various levels of foreign material to achieve the maximum allowed. It only limits the procedure by which the maximum may be achieved. In addition, some if not most of the "foreign material" in overseas processing plants is broken grain created during unloading of vessels. Consequently, it is unlikely that the actual amount of "foreign material" delivered to the foreign buyer will change, but it may be more expensive to attain the contract levels at the export elevator.

The most basic problem is one of trying to legislate restrictions to counter the economic incentives built into the standards themselves. Having an allowance of 4 percent BCFM in No. 3 corn builds in an automatic incentive to add that much foreign material to the load when corn is purchased on the grade alone. Removing that incentive would be more efficient than a prohibition. If a set of standards can be established that creates incentives to achieve the desired end product in terms of quality, the legislative prohibition would become unnecessary.

FINDINGS AND CONCLUSIONS

Continual review of grain standards since their inception in the 1916 United States Grain Standards Act has generated numerous changes and proposals for change in factors and factor limits. These have not resolved the problems or foreign complaints related to quality. U.S. grain standards today:

- create incentives for practices not consistent with good management and efficiency;
- fail to identify many of the characteristics related to value in use;
- fail to reward producers and handlers for improved drying, harvesting, handling, and variety selection; and
- include arbitrary grade limitations on many factors that do not always reflect real differences in value, and in some cases are not consistent with statistical principles.

The many regulatory and legislative standard changes have failed to move the industry in a consistent direction. In fact, there have been numerous reversals of previous changes. What has been lacking is a clearly defined goal toward which the system is being moved. With the four objectives for standards now established by legislation, it is possible to develop for each grain a set of "ideal" standards that could provide a direction for future changes and a yardstick against which to evaluate alternatives. If each change adopted moves the operational standards closer to the ideal, repeated reversals should no longer create unnecessary adjustment costs and confusion in domestic and foreign markets.

Conflicts between purposes can be explicitly identified and the trade-offs and economic consequences calculated and recorded as guidance for a long-range consistent policy. The ideal system should include grade-determining factors, non-grade-determining factors, and definition and measurement technology for official criteria.

Existing research is generally adequate to identify grade-determining factors—sanitary quality factors, damage that reduces yield and quality of processed products or value in use, and foreign material including dust. For No. 1 grade, these factor limits should be set as close to zero as measurement technology will allow. Any value above zero violates the third and fourth purposes of grades. The exact definition of these factors, including sieve size for foreign material, still requires additional research to evaluate the alternatives against the criterion of reflecting value accurately.

Non-grade-determining factors should measure value for a majority of users. The preferred level may differ among uses. For example, splits in soybean reduce oil quality only in proportion to the time in storage. Thus, domestic processors buying for immediate use may allow high levels of splits with no discounts. Foreign buyers, whose processing of the soybeans may lag harvest by 12 to 18 months, may place much more restrictive limits and discounts on splits.

Many of the intrinsic and physical properties that influence the quantity and quality of products derived from the grain have not been identified. More research may add to the list of properties to be included. The criteria for inclusion should be that the cost of obtaining the information is less than the value of that information to users who need the information. By starting with the major products generated from each grain, a list of physical and intrinsic properties can be developed that correlates with value in use. New, rapid objective testing technology is also a requirement prior to inclusion.

The list of factors to be measured under official criteria is almost unlimited except by measurement technology. Any properties that can be accurately measured can be requested by buyers and sellers. These would be developed only after evidence of sufficient demand to cover the cost. Information on the factors of interest for the various users could be provided by private laboratories and would be added to official criteria only after rapid objective technology is developed and when there is sufficient demand by domestic or foreign buyers to justify including them.

Standards should be designed to reward positive actions, such as genetic improvement, and sound harvesting, drying, and marketing practices. They should also be designed to provide the best information available on the value of each shipment by descriptive terminology. All changes must be evaluated against the criterion of providing information that is worth the cost of obtaining it. Optimum information, not maximum information, is the goal. Proposals for change must also be tempered with current capabilities of the industry, the cost of adjustments v. potential benefits, the realities of international trading rules, and the historical sequence by which the industry has attained the present situation. Measurement and description of quality is only one part of the problem. Quality must be evaluated in the context of technology, competition, foreign demand, and processing requirements.

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Chapter 9

Government Farm Policy and Economic Incentives Affecting Quality

Government farm policy and varying governmental economic incentives to the grain system have a significant influence on grain quality. Government farm programs in particular play an essential role in providing incentives to farmers to produce a range of crop quantity and quality. In commodities such as wheat, soybeans, and corn, where biological trade-offs exist between yield and a major quality factor like protein, farm programs potentially have important impacts on quality.

Farm programs have played a key role in U.S. agriculture since at least the mid-1930s (4). The numerous programs have shifted gradually from price supports to income supports. The constraints and incentives they provide are transmitted throughout the production and marketing system and consequently may have an impact on grain quality. Two provisions are particularly important—the loan rate program and its associated premiums and discounts for quality differentials, and the target price program, which results in higher prices associated with yield. To the extent that yield and quality are inversely related (see ch. 6), any program resulting in increased yields also has the potential to reduce quality.

This chapter looks at the impacts of farm programs on grain quality, which have historically been stronger than they are today. It reviews farm program legislation with a focus on its impacts on grain quality, analyzes the extent of and dynamics in the trade-offs between yield and quality, and considers potential impacts of higher prices on incentives to increase yields and decrease quality.

The analysis focuses on wheat because data are more easily attained. But the principle can be applied to any grain in which commercial premiums and discounts exist for particular quality characteristics, and in which measurable trade-offs exist in production between yield and quality. In the two classes of wheat discussed here—Hard Red Spring (HRS), predominantly grown in North Dakota, and Hard Red Winter (HRW), in which Kansas is the leading State—premiums and discounts play an important role in the marketing system and yield is inversely related to protein, an important quality characteristic.

GOVERNMENT PROGRAM EFFECTS ON GRAIN QUALITY

One of the main purposes of government farm policies since World War II has been to support farm incomes. Several different policies and programs have been used over time to achieve this goal. Loan rate provisions have been in effect in wheat programs since before the war. The target price/deficiency payment system has been used since 1973; it did not have major effects until 1977, however, because market prices at first exceeded the loan rate and in some cases the target price.

Wheat program participation prior to 1964 was mandatory in most years. Acreage allotments were imposed along with marketing quotas in 1951 and from 1954 to 1963 (1). The allotments were set at the amount of acreage needed to produce a crop that, together with carry-over and imports, would provide a supply equal to a normal year's domestic consumption and exports plus an allowance for reserves. Marketing quotas were used along with acreage allotments as a more stringent means of controlling output. When expected supply for a year exceeded estimated use by a specified amount, marketing quotas had to be proclaimed by the Secretary of Agriculture. A quota became effective by a two-thirds vote of approval by wheat producers. When marketing quotas were approved, compliance with acreage allotment was mandatory; when they were not approved, the level of price supports was lowered substantially.

Beginning in 1964, farm programs no longer required mandatory participation and marketing quotas were voted out. From 1964 to 1973, loan rates were reduced and farm income was supported by domestic certificate and export certificate payments in cash, based on a percentage of production on a farmer's allotted acres.

In 1973 marketing certificates were replaced by target price/deficiency payments as a means of supporting farm income. From 1974 to 1976, wheat prices increased dramatically and were higher than loan rates. Hence, government participation in the form of income support to wheat producers, directly or via prices, was virtually nonexistent. Implementation of the target price program did not effectively begin until 1977 and is still in effect today. The per-bushel income support payment (called a deficiency payment) is the difference between the target price and the average price received by farmers in the first 5 months of the marketing year, or between the target price and the loan rate, whichever is higher. Historical loan rates, target prices, and deficiency payments are presented in table 9-1. Deficiency payments increased dramatically in 1984 and have since nearly doubled. As a result, in recent years payments that are by definition based on yield account for an increasing proportion of a producer's income.

A producer's total payment is calculated by multiplying the per-bushel deficiency payment times the program acres and then times the proven yield. Program acres are a historical average of acres planted to wheat, and proven yield is a historical, 5-year moving average of an individual producer's past yields. These historical averages change over time, meaning producers increase or decrease the program acres devoted to wheat and increase proven yield by altering variety choices or production practices. The incentive encourages them to maximize proven yields in order to achieve the highest deficiency payment possible.

The Food Security Act of 1985, the most recent major farm legislation, made several changes in the loan rate and target price provisions. The loan rate for wheat in 1986 was reduced 20 percent, from $3.30/bushel to $2.40, while the target price remained at $4.38/bushel for 1986. This meant that with market prices

Table 9-1.—Loan Rates, Target Prices, and Deficiency Payments for Wheat in the United States, 1974-86
(in dollars/bushel)

Year	National average market price	Loan rate	Target price	Actual deficiency payment	Deficiency payments as proportion of target price (percent)
1974	4.09	1.37	2.05	—	—
1975	3.56	1.37	2.05	—	—
1976	2.73	2.25	2.29	—	—
1977	2.33	2.25	2.90	0.65	22.4
1978	2.97	2.35	3.40	0.52	15.3
1979	3.78	2.50	3.40	—	—
1980	3.91	3.00/3.30	3.08/3.63	—	—
1981	3.65	3.20/3.50	3.81	0.15	3.9
1982	3.55	3.55/4.00	4.05	0.50	12.3
1983	3.53	3.65	4.30	0.65	15.1
1984	3.38	3.30	4.38	1.00	22.8
1985	3.08	3.30	4.38	1.08	24.6
1986	2.40	2.40	4.38	1.98	45.2

SOURCE: U.S. Department of Agriculture, Statistical Reporting Service, *Agricultural Statistics*, various issues.

near the loan rate, the deficiency payment increased from $1.08/bushel to $1.98/bushel in 1986.

Loan Rate Program Premiums and Discounts

The loan rate program was the primary mechanism for price support prior to 1973 and continues to be an important form of support. A key component of the loan rate program is the provision that allows for adjustment in the loan price a farmer receives based on quality differentials. Each year a schedule of premiums and discounts is published in the provisions for the loan rate program. In addition, the market establishes premiums and discounts reflecting the market-determined value of quality attributes. These provide incentives with the potential to influence yields and the allocation of wheat between the market and government via loan forfeitures. This allocation may take place within as well as between crop years. Administration of the loan rate program has included premiums for protein above a certain level and discounts for grade differentials. In addition, discounts originally used for loan rate adjustments have changed over time.

Protein premiums as provided by the loan rate program have been relatively stable (table 9-2). The premium applicable to HRW 13 percent protein over HRW 10.5 percent protein has been 4.5 cents/bushel since 1965 with the exception of 1973 and 1974, when it decreased to 4.25 cents/bushel. From 1950 to 1965 the premium for HRW 13 percent protein rose from 3 cents to 4 cents/bushel. Throughout the 1950s and early 1960s the protein premium for HRS 15 percent protein was 6 cents/bushel; it reached 10.5 cents/bushel from 1965 to 1976; and it increased to 16 cents/bushel in 1977.

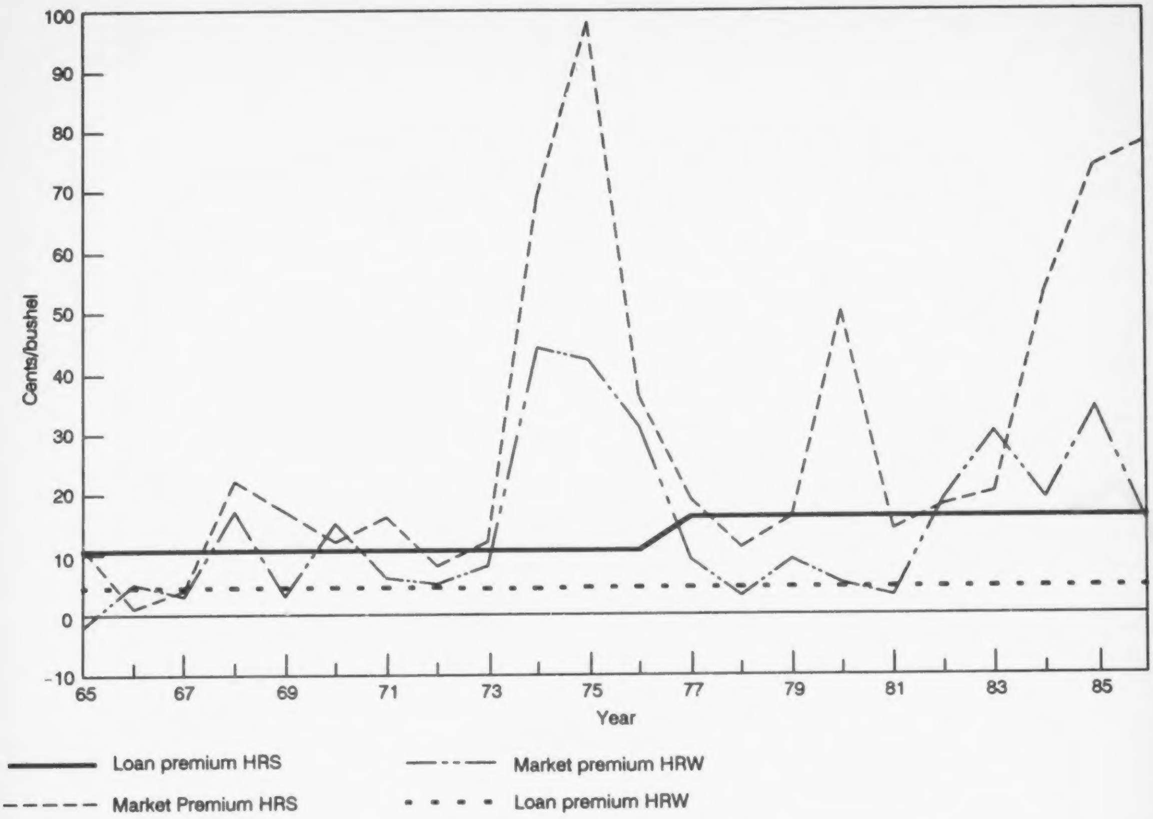
The loan rate premium has been less than the market premium in most of the past 22 years (figure 9-1). The market premium was lower in only 5 years for both HRS and HRW. The spread between the loan rate and market premiums has been increasing steadily since

Table 9-2.—Loan Rates and Market Premiums for HRS and HRW, 1965-86 (cents/bushel)

	HRW			HRS		
Market year	Loan rate premium 13% over 10.5%[a]	Market premium 13% over ordinary[b]	Difference	Loan rate premium 15% over 11.5%[a]	Market premium 15% over 12%[c]	Difference
1965	4.50	−2	−6.50	10.50	11	0.50
1966	4.50	5	0.50	10.50	1	−9.50
1967	4.50	3	−1.50	10.50	4	−6.50
1968	4.50	17	12.50	10.50	22	11.50
1969	4.50	3	−1.50	10.50	17	6.50
1970	4.50	15	10.50	10.50	12	1.50
1971	4.50	6	1.50	10.50	16	5.50
1972	4.50	5	0.50	10.50	8	−2.50
1973	4.25	8	3.75	10.50	12	−1.50
1974	4.25	44	39.75	10.50	69	58.50
1975	4.50	42	37.50	10.50	98	87.50
1976	4.50	31	26.50	10.50	36	25.50
1977	4.50	9	4.50	16.00	19	3.00
1978	4.50	3	−1.50	16.00	11	−5.00
1979	4.50	9	4.50	16.00	16	0.00
1980	4.50	5	0.50	16.00	50	34.00
1981	4.50	3	−1.50	16.00	14	−2.00
1982	4.50	19	14.50	16.00	18	2.00
1983	4.50	30	25.50	16.00	20	4.00
1984	4.50	19	14.50	16.00	53	37.00
1885	4.50	34	29.50	16.00	74	58.00
1986	4.50	15	10.50	16.00	78	62.00

[a] U.S. Department of Agriculture (USDA), Agricultural Stabilization and Conservation Service, "Schedule of Premiums and Discounts," various issues.
[b] USDA, Economic Research Service, "Wheat Outlook and Situation," various issues.
[c] Minneapolis Grain Exchange, *Statistical Annual*, various issues.

Figure 9-1.—Historical Loan Rate and Market Protein Premium for HRS 15 Percent and HRW 13 Percent, 1965-86



SOURCE: Office of Technology Assessment, 1989

1982. In general, the loan rate premiums for protein have not reflected market fundamentals, and this spread has been increasing in recent years in both the HRW and HRS market. This situation has a potential to distort production decisions of variety choice and fertilizer application to the extent that a trade-off exists between yield and protein. Storage decisions are also likely distorted by the disparity in government and market protein premiums. Producers have the incentive to put low-protein wheat under loan and to forfeit the loan if market prices for that type of wheat do not appreciate. The market premium is typically high enough to encourage commercial sales of higher protein wheat. Consequently, the program spreads relative to the market result in isolating lower protein wheat from the market, and may to some extent discourage development and adoption of lower protein varieties.

Other features of the loan rate program have changed over time. Prior to 1973, two other measures were used to reflect quality in program prices. The first was called a sedimentation test, which measures the quality of protein content in wheat (5). This test is performed by suspending ground wheat in water and treating it with lactic acid. The portion that within 5 minutes settles to the bottom of a graduated cylinder is the sedimentation value. Values range from 3 for very weak wheat to 70 for very strong wheat. Premiums and discounts for different sedimentation values were used during 1963 and 1964 (table 9-3).

The second measure was the discounts associated with varieties, which was used throughout the 1960s and up through 1972. Discounts were applied on varieties in each class of wheat deemed "undesirable" due to poor quality characteristics. (The term "undesirable" was used in the schedule of premiums and discounts.) The varieties and number of varieties changed over time to reflect newly released wheats. Generally, a half-dozen varieties were subject to discount in any given year. Examples of "undesirable" HRW varieties in the early 1970s included Blue Jacket, Purkof, Cache, Red Chief, Staffor, and Yogo. Examples of "undesirable" HRS varieties included Red River 68, Era, and Neepawa. The discount was 20 cents/bushel throughout this period. This discount ended in 1973 and is no longer used.

Wheat is subject to other premiums and discounts under the loan program. These are applied by grade and not on an individual factor basis as long as the grade is "sample" or better (table 9-4). Additional discounts based on factors do apply on test weight and damage if the wheat is No. 4, No. 5, or sample grade in specific years (tables 9-4, 9-5, and 9-6). The discounts applied to damaged kernels were substantially reduced beginning in 1980.

Table 9-3.—Sedimentation Value Premiums and Discounts Provided by Loan Rate Program, 1963 and 1964

Sedimentation value, 1963	Premium or discount, 1963 (cents/bushel)	Sedimentation value, 1964	Premium or discount, 1964 (cents/bushel)
21 and below	−9	22 and below	−6
22-23	−8	23-25	−5
24-25	−7	26-28	−4
26-27	−6	29-31	−3
28-29	−5	32-34	−2
30-31	−4	35-37	−1
32-33	−3	38-42	0
34-35	−2	43-45	+1
36-37	−1	46-48	+2
38-42	0	49-51	+3
43-44	+1	52-54	+4
45-46	+2	55-57	+5
47-48	+3	58-60	+6
49-50	+4	61-63	+7
51-52	+5	64-66	+8
53-54	+6	67 and above	+9
55-56	+7		
57-58	+8		
59-60	+9		
61-62	+10		
63-64	+11		
65 and over	+12		

SOURCE: U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, "Schedule of Premiums and Discounts," various issues.

Market premiums and discounts for grade factors are measured differently than those in the loan rate provisions. In market transactions, discounts are normally taken for individual factors such as test weight, damaged kernels, or foreign material (table 9-7).

It is difficult to compare market discounts with loan rate discounts because they are not quoted on the same basis. In general, the loan rate discounts by grade while the market discounts on the individual factors that determine grade. Individual wheat factors that determine grade are presented in table 9-8. Comparisons must be tentative when using the quoted market discounts and premiums because they are for a particular point in time and, even though they may represent the market as a whole, they do change.

Damage has been one of the more limiting factors in recent years in grade determination in HRS and is used here for comparison. The market discount for a sample with 4 percent damage would be 10 cents assuming no other factor discounts. For comparison, 4-percent-damaged kernels would be graded No. 2 and would result in a 2 cents/bushel discount from the loan rate. Thus, market discounts are substantially greater than those in the loan rate program; if other factor discounts were also included (e.g., test weight or foreign matter), the comparison would be even more dramatic.

Annual surveys of country elevators in North Dakota on discounting practices suggest that, in general, market premiums and discounts have increased in the past 3 years (table 9-9). For example, the discount for 4-percent-damaged kernels (i.e., No. 2) rose from an elevator average of 2 cents in 1984 to 8.9 cents in 1986.

The individual factors for discount in table 9-4 are the factor levels allowable in order for

Table 9-4.—Loan Rate Premiums and Discounts on Wheat by Grade (cents/bushel)

Year	No. 1	No. 2	No. 3	No. 4[a]	No. 5[a]	No. 4 No. 5[b]
1954-61	+1[c]	−1	−3	−6	−9	−6
1962	+1[c]	−1	−3	([d])	([d])	−6
1963	+1[c]	−1	−3	−6	−9	−6
1964	+1[c]	−1	−2	([d])	([d])	−6
1965-76	+2[e]	−1	−3	−6	−9	N/A
1977-86	0	−2	−4	−6	−9	N/A

[a] On test weight otherwise No. 3.
[b] No. 4 or No. 5 because containing Durum and or red Durum.
[c] $0.01 premium for No. 1 heavy.
[d] Test weight discount for No. 4, No. 5, or sample.
[e] No. 3 or better heavy.

SOURCE: U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, "Schedule of Premiums and Discounts," various issues.

Table 9-5.—Additional Loan Rate Discounts on Wheat for Test Weight[a] (cents/bushel)

Test weight	1962	1964
53 to 54.9	−6	−4
50 to 52.9	−9	−6
49	−13	−9
48	−17	−12
47	−21	−15
46	−25	−18
45	−29	−21
44	−35	−25
43	−41	−29
42	−47	−33
41	−53	−37
40	−59	−41

[a] Applicable if wheat is No. 4, No. 5, or sample grade.

SOURCE: U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, "Schedule of Premiums and Discounts," various issues.

wheat to grade No. 2. In adding up the discounts for each factor except protein, the total possible discount for wheat (i.e., on all factors to the limit) that grades No. 2 by the market according to the survey was 36 cents/bushel in 1986. The discount for wheat grading No. 2 by the loan rate program is 2 cents/bushel. Wheat must meet the limit of only one of the factors listed in table 9-8 (except moisture and protein) in order to grade No. 2. In reality wheat would not likely be discounted by all factors, and only one or two factors would be limiting for discount purposes. Generally, damaged kernels have been one of the more limiting factors in grade determination in this time period. The discount for 4-percent-damaged kernels was 8.9 cents in 1986, assuming all other factor discounts would apply, while the loan program discount No. 2 wheat would have been 2 cents/bushel.

The differential between the loan rate and the market premiums and discounts—a differential that is apparently growing—has a significant impact. Most important is the allocation of wheat with different qualities between the loan program and market. In general, this differential results in higher quality wheat being sold commercially, while the poorer quality wheat, being subject to greater market discounts, is put under loan and stored since the applicable discounts would be substantially lower. (Domestic millers have methods of determining where the higher quality wheats are located and can purchase by location. Millers can also specify other factors such as falling numbers, pesticide residue, and sedimentation before shipment.) With market prices hovering around loan levels, this wheat has the potential of being stored for an extended time and of being released to the market only gradually.

For comparison, if loan rate premiums or discounts reflected or exceeded those of the market, the incidence of relatively poor quality wheat would likely not be reduced due to much of it being weather-related. Rather, it would result in poor quality wheat being sold to the market directly, rather than being put under loan and stored. In this case the loan rate would support prices of the higher quality grain, rather than that of lower quality, as is currently the case.

Table 9-6.—Additional Loan Rate Discounts for Damaged Kernels in Wheat (in cents/bushel)

Total percent damage	1951 No. 4 or No. 5	1962 No. 4, No. 5 or sample	1977 & 1978 sample	1980-86 sample
7.1 to 8.0	−1	−1	N/A	N/A
8.1 to 9.0	−2	−2	N/A	N/A
9.1 to 10.0	−3	−3	N/A	N/A
10.1 to 11.0	−4	−4	N/A	N/A
11.1 to 12.0	−5	−5	N/A	N/A
12.1 to 13.0	−6	−6	N/A	N/A
13.1 to 14.0	−7	−7	N/A	N/A
14.1 to 15.0	−8	−8	N/A	N/A
15.1 to 16.0	N/A	−10	−10	−2
16.1 to 17.0	N/A	−12	−12	−4
17.1 to 18.0	N/A	−14	−14	−6
18.1 to 19.0	N/A	−16	−16	−8
19.1 to 20.0	N/A	−18	−18	10
20.1 to 21.0	N/A	−20	−20	−12
21.1 to 22.0	N/A	−22	−22	−14
22.1 to 23.0	N/A	−24	−24	−16
23.1 to 24 0	N/A	−26	−26	−18
24.1 to 25.0	N/A	−28	−28	−20
25.1 to 26.0	N/A	−30	−30	−22
26.1 to 27.0	N/A	−32	−32	−24
27.1 to 28.0	N/A	−34	−34	−26
28.1 to 29.0	N/A	−36	−36	−28
29.1 to 30.0	N/A	−38	−38	−30
over 30.1	N/A	−60	3 cents each percent over 30.0	3 cents each percent over 30.0

N/A = not available

SOURCE: U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, "Schedule of Premiums and Discounts," various issues.

Table 9-7.—Market Discounts for HRS, February 1987

Item	Discounts
Test weight	2¢ each ½# 58-56#, 3¢ each ½# 56-54#, 5¢ each ½# 54-56
Moisture	1¢ each ¼# 13.5-14.0% maximum
Foreign material	1¢ ½% 0.5-5% maximum
Damage	2¢ each 1% 0-3% (0.9 allowed) 4¢ each 1% 3-5% 6¢ each 1% 5-7%
Sprout damage	2¢ each 0.5% over 0.5-5% maximum
Shrunk and broken	1¢ each 1% 3-5% 2¢ each 1% 5-15%
Total defects	1¢ over 3-5%
Wheat of other classes	2¢ each 1% over 3-10% maximum
Contrasting classes	1¢ each 1% 1-10% maximum

SOURCE: Continental Grain Co., 1988.

Farm Programs and Variety Selection

One impact of farm programs is that they may distort producers' choices regarding variety selection. Given an inverse relationship between yield and quality characteristics (protein in this case), any farm program not adequately discounting for quality deviation will have an effect on agronomic practices. This section presents a budget analysis of the impacts of loan rate protein premiums and deficiency pay-

Table 9-8.—Wheat Quality Factors Determining Grade Standards

	Minimum limits of—		Maximum limits of—						
	Test weight per bushel								
			Damaged kernels					Wheat or other classes[d]	
Grade	Hard Red Spring wheat or White Club wheat[a] (pounds)	All other classes and subclasses (pounds)	Heat-damaged kernels (percent)	Total[b] (percent)	Foreign material (percent)	Shrunken and broken kernels (percent)	Defects[c] (percent)	Contrasting classes (percent)	Total[e] (percent)
U.S. No. 1	58.0	60.0	0.2	2.0	0.5	3.0	3.0	1.0	3.0
U.S. No. 2	57.0	58.0	0.2	4.0	1.0	5.0	5.0	2.0	5.0
U.S. No. 3	55.0	56.0	0.5	7.0	2.0	8.0	8.0	3.0	10.0
U.S. No. 4	53.0	54.0	1.0	10.0	3.0	12.0	12.0	10.0	10.0
U.S. No. 5	50.0	51.0	3.0	15.0	5.0	20.0	20.0	10.0	10.0

U.S. Sample grade:

U.S. Sample grade is wheat that:

a. Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

b. Contains 32 or more insect-damaged kernels per 100 grams of wheat; or

c. Contains 8 or more stones or any number of stones which have an aggregate weight in excess of 0.2 percent of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds *(Crotalaria* spp.), 2 or more castor beans *(Ricinus communis* L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 2 or more rodent pellets, bird droppings, or equivalent quantity of other animal filth per 1,000 grams of wheat; or

d. Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor); or

e. Is heating or otherwise of distinctly low quality.

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[a] These requirements also apply when Hard Red Spring or White Club wheat predominate in a sample of Mixed wheat.

[b] Includes heat-damaged kernels.

[c] Defects include damaged kernels (total), foreign material, and shrunken and broken kernels. The sum of these three factors may not exceed the limit for defects for each numerical grade.

[d] Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.

[e] Includes contrasting classes.

SOURCE: Federal Grain Inspection Service, U.S. Department of Agriculture, 1988.

Table 9-9.—Average Price Adjustments for Each Factor Among North Dakota Country Elevators, Fall 1984, 1985, and 1986 (cents/bushel)

Commodity (base grade)	Factor	1984 average	1985 average	1986 average
HRS	57 lbs. test weight	−1.9	−1.8	−2.9
#1 DNS	14.5% moisture	−5.9	−6.8	−6.5
14% Protein	16% protein	41.0	63.4	62.6
	12% protein	−38.0	−67.4	−43.9
	4% damaged kernels	−2.0	−6.6	−8.9
	1% foreign material	−1.4	−1.3	−1.7
	5% shrunken and broken kernels	−2.2	−3.0	−4.2
	2% contrasting classes	−1.6	−3.2	−3.5
	5% wheat of other classes	—	−7.0	−8.6

SOURCE: B. Clow, W. Wilson, and R. Hielman, "Pricing and Marketing Practices for North Dakota Durum and HRS Wheat 1986 Crop Year," Department of Agricultural Economics, North Dakota State University, Fargo, ND, 1987.

ments. Typical producer situations are posed for a North Dakotan and a Kansan wheat producer from 1965 to 1986.

The measure used in this analysis is total revenue. Costs per acre are assumed the same across varieties. The protein premiums used for HRS were the government loan rate premium and the market premium for 14 percent and 15 percent protein; for HRW, the premiums used were for 13 percent and 11 percent protein. Government program impacts were incorporated into the analysis in that target price instead of market price was used to calculate total revenue. This assumes 100 percent participation in government programs. Yield used in the analysis was 30 bushels/acre for HRS 14 percent protein and 25 bushels/acre for HRS 15 percent protein in order to reflect a typical yield/protein trade-off. For HRW, the figures used were 35 bushels/acre for 13 percent protein and 41 bushels/acre for 11 percent protein. Total revenue was calculated by adding the market protein premium or government premium to target price and multiplying this sum by the yield per acre.

Total revenues under the market premium condition and the government premium condition would be relatively similar in these hypothetical cases except for two brief periods (tables 9-10 and 9-11). In the mid-1970s and 1980s, when market premiums were much higher, total revenue would be greater under them than under the government premium.

Of particular interest is the revenues per acre achievable under the loan program. The farm programs have always favored higher yielding wheats, but the difference increased during the 1980s. In 1969 the difference in North Dakota was $9/acre; in 1979 it was $16/acre. Since then the spread favoring production of higher yielding wheats has increased to $20/acre. Similar results were observed in Kansas.

The shift toward higher yielding varieties forces the market premium to increase in order to achieve a certain level of protein. To analyze the potential impacts, the producer budgets just described were calculated under various yield scenarios in order to determine the protein premiums necessary for a producer to be indifferent about using high- or low-yielding wheat. In the case of North Dakota, the total revenue was equated to $144/acre, which corresponds with production of 30 bushels/acre and 14 percent protein in table 9-10.

The results are shown in table 9-12 for various yield levels, but in each case protein was 15 percent and total revenue was constrained to $144/acre. For example, if a producer could achieve an increase of 1 percent protein with a decrease in yield of 1 bushel/acre, the premium necessary for $144/acre is 53 cents/bushel. A more realistic situation is where 3 bushels/acre would be foregone to increase protein 1 percent. In this case the protein premium would have to increase to 75 cents/bushel per 1 percent of protein.

The protein premium needed to neutralize a producer's decision to produce 14 percent or 15 percent protein wheat increases rapidly as the yield difference increases. This is caused

Table 9-10.—Theoretical Revenue for a One-Acre Farm in North Dakota, 1965-86

		25 bushel/acre/15% protein				30 bushel/acre/14% protein			
		Protein premium (dollars/bushel)		Revenue per acre (dollars/acre)		Protein premium (dollars/bushel)		Revenue per acre (dollars/acre)	
Year	Target price[a]	Market	Loan rate	Market[b]	Loan rate[c]	Market	Loan rate	Market[b]	Loan rate[c]
1965	1.69	0.11	0.105	45	45	0.060	0.075	53	53
1966	1.84	0.01	0.105	46	49	0.010	0.075	56	57
1967	1.73	0.04	0.105	44	46	0.040	0.075	53	54
1968	1.80	0.22	0.105	51	48	0.100	0.075	57	56
1969	1.89	0.17	0.105	52	50	0.070	0.075	59	59
1970	2.00	0.12	0.105	53	53	0.020	0.075	61	62
1971	1.79	0.16	0.105	49	47	0.150	0.075	58	56
1972	1.72	0.08	0.105	45	46	0.080	0.075	54	54
1973	1.47	0.12	0.105	40	39	0.120	0.075	48	46
1974	2.05	0.44	0.105	62	54	0.280	0.075	70	64
1975	2.05	0.71	0.105	69	54	0.440	0.075	75	64
1976	2.29	0.36	0.105	66	60	0.230	0.075	76	71
1977	2.90	0.19	0.160	77	77	0.110	0.090	90	90
1978	3.40	0.11	0.160	88	89	0.035	0.090	103	105
1979	3.40	0.16	0.160	89	89	0.010	0.090	102	105
1980	3.63	0.50	0.160	103	95	0.220	0.090	116	112
1981	3.81	0.14	0.160	99	99	0.060	0.090	116	117
1982	4.05	0.18	0.160	106	105	0.090	0.090	125	125
1983	4.30	0.20	0.160	113	112	0.150	0.090	134	132
1984	4.38	0.53	0.160	123	114	0.300	0.090	140	134
1985	4.38	0.74	0.160	128	114	0.420	0.090	144	134
1986	4.38	0.78	0.160	129	114	0.430	0.090	144	134

[a] Prior to 1973 target price is blended average price to program participants reflecting national average price received by farmers and the marketing certificate value averaged for participant's total production. Post-1973 target price is loan rate plus deficiency payment.

[b] Revenue is market premium plus target price times yield.

[c] Revenue is government premium plus target price times yield.

SOURCE: U.S. Department of Agriculture, Statistical Reporting Service, *Agricultural Statistics*, various issues.

by the target price deficiency payment program, which pays a producer $1.98/bushel more than the market. Thus the opportunity cost of decreasing yield and increasing protein is $4.38 (target price). This creates a high-protein premium needed to render a producer indifferent between producing 14 percent and 15 percent protein wheat. Similar results are shown in table 9-13 for HRW wheat in Kansas.

Government Storage Policies

The Commodity Credit Corporation (CCC) of the U.S. Department of Agriculture (USDA) enters into agreements with commercial warehouses to handle and store grain. This covers grain owned by CCC, pledged to the agency as collateral under the price support program, delivered to the warehouse for purchase by CCC under a price support program, delivered to the warehouse in liquidation of a price support loan, or held by CCC for any other reason. The contractual agreement is referred to as the Uniform Grain Storage Agreement (UGSA). It covers areas such as standards for approving warehouses, inspection requirements, load out and delivery requirements, and settlement procedures (3).

Warehouses, for the purpose of applying the UGSA, are defined on the basis of whether inspections sponsored by the Federal Grain Inspection Service (hereafter referred to as "official inspection") and UGSA-approved weights are available. Country elevators are those locations where official inspections and UGSA weights are not available, while terminal elevators do have these available. Within the UGSA, different rules apply to country and terminal warehouses.

Inspection requirements obviously differ since the distinction between country and terminal elevators is based on whether official inspection is available. In general, grain shipped into and out of terminal elevators must be officially inspected. However, CCC retains the right to have quality determined at other points

Table 9-11.—Theoretical Revenue for a One-Acre Farm in Kansas, 1965-86

		25 bushel/acre/15% protein				30 bushel/acre/14% protein			
		Protein premium (dollars/bushel)		Revenue per acre (dollars/acre)		Protein premium (dollars/bushel)		Revenue per acre (dollars/acre)	
Year	Target price[a]	Market	Loan rate	Market[b]	Loan rate[c]	Market	Loan rate	Market[b]	Loan rate[c]
1965	1.69	−0.02	0.0450	58	61	—	—	69	69
1966	1.84	0.05	0.0450	66	66	—	—	75	75
1967	1.73	0.03	0.0450	62	62	—	—	71	71
1968	1.80	0.17	0.0450	69	65	—	—	74	74
1969	1.89	0.03	0.0450	67	68	—	—	77	77
1970	2.00	0.15	0.0450	75	72	—	—	82	82
1971	1.79	0.06	0.0450	65	64	—	—	73	73
1972	1.72	0.05	0.0450	62	62	—	—	71	71
1973	1.47	0.08	0.0425	54	53	—	—	60	60
1974	2.05	0.44	0.0425	87	73	—	—	84	84
1975	2.05	0.42	0.0450	86	72	—	—	84	84
1976	2.29	0.31	0.0450	91	81	—	—	94	94
1977	2.90	0.09	0.0450	105	103	—	0.005	119	119
1978	3.40	0.03	0.0450	120	121	—	0.005	139	139
1979	3.40	0.09	0.0450	122	120	—	0.005	139	139
1980	3.63	0.05	0.0450	129	129	—	0.005	149	150
1981	3.81	0.03	0.0450	134	135	—	0.005	156	156
1982	4.05	0.19	0.0450	148	143	—	0.005	166	166
1983	4.30	0.30	0.0450	161	152	—	0.005	176	177
1984	4.38	0.19	0.0450	160	155	—	0.005	180	180
1985	4.38	0.34	0.0450	165	155	—	0.005	180	180
1986	4.38	0.15	0.0450	159	155	—	0.005	180	180

[a] Prior to 1973 target price is blended average price to program participants reflecting national average price received by farmers and the marketing certificate value averaged for participant's total production. Post-1973 target prices is loan rate plus deficiency payment.

[b] Revenue is market premium plus target price times yield.

[c] Revenue is government premium plus target price times yield.

SOURCE: U.S. Department of Agriculture, Statistical Reporting Service, "Agricultural Statistics," various issues.

Table 9-12.—Implied Premium Necessary for HRS Producers To Be Indifferent About Growing 14 or 15 Percent Protein Wheat

Yield (bushel/acre)	Protein (percent)	Premium[a] (dollars/bushel)	Loan rate (dollars/bushel)	Revenue[b] (dollars/acre)
29	15	0.53	2.40	144
28	15	0.64	2.40	144
27	15	0.75	2.40	144
26	15	0.87	2.40	144
25	15	1.00	2.40	144

[a] Premiums are derived from equating TR to $144/acre.

[b] Revenue (TR) was derived as $TR = Y_p \bullet DP + (Y_a \bullet P_0) + Y_a \bullet \text{Premium}$ where Y_p is proven yield (30 in this case), DP is the deficiency payment, Y_a is actual yield (29 . . . 25), P_0 is market price or loan rate.

SOURCE: Office of Technology Assessment, 1989.

and as agreed to by the warehouse operation and CCC. The quality of producer deliveries for liquidating price support loans at terminal elevators is determined as agreed to by producer and warehouse receiver.

Quality determination on grain received into country elevators is based on agreement either between the warehouse and CCC or between producer and the warehouse. For grain loaded out of country elevators by truck, quality is determined on the basis and at a point specified in the CCC loading order. For all other carriers, it is obtained at destination or at a point specified in the loading order.

When grain is accepted for storage, the warehouse operator must issue negotiable warehouse receipts that show results for all factors contained in the grain standards and furnish

Table 9-13.—Implied Premium Necessary for HRW Producers To Be Indifferent About Growing 11 or 13 Percent Protein Wheat

Yield (bushel/acre)	Protein (percent)	Premium[a] (dollars/bushel)	Loan rate (dollars/bushel)	Revenue[b] (dollars/acre)
39	13	0.10	2.40	179
37	13	0.24	2.40	179
35	13	0.39	2.40	179
33	13	0.56	2.40	179
31	13	0.75	2.40	179

[a] Premiums are derived from equating TR to $179/acre.

[b] Revenue (TR) was derived as $TR = Y_p \bullet DP + (Y_a \bullet P_0) + Y_a \bullet \text{Premium}$ where Y_p is proven yield (41 in this case), DP is the deficiency payment, Y_a is actual yield (39 . . . 31), P_0 is market price or loan rate.

SOURCE: Office of Technology Assessment, 1989.

all weight and quality certificates to CCC. These receipts are then used to determine the quantity and quality of the grain being stored for CCC and as the basis for issuing loading orders. CCC uses the individual factor results reported on the various warehouse receipts for computerized blending to arrive at weighted average grade and factor results. These averages then serve as the grade and weighted average quality that appears on the loading order. In some cases, this has resulted in a higher grade than is represented by any of the warehouse receipts (2). For example, grain at grade Nos. 2, 3, and 4 can be blended to arrive at a weighted average grade of No. 1 even though no individual warehouse receipts have been issued for No. 1.

Recently CCC amended the UGSA regarding load out and delivery requirements for terminal elevators in order to restrict computerized blending to three broad categories. Factor results for grade Nos. 1, 2, and 3 will be blended together as one category, factor results from grade Nos. 4 and 5 as the second category, and results from sample grade as the third. The amendment also specifies that blending should not result in a weighted average quality of a higher grade than reported on at least one-third of the warehouse receipts used as the basis for determining quality.

Load out and delivery requirements contained in the UGSA call for the warehouse to deliver the grain ordered shipped by CCC. At both country and terminal elevators, the qualities represented by the warehouse receipts serve as the basis for the load out quality requirements. When CCC surrenders receipts representing a specific grade with weighted average quality to a terminal elevator, each shipment must meet the specific grade and weighted average results. CCC can request a unit shipment (a minimum 10 railcars shipped on the same bill of lading to comply with a tariff that offers rate incentive). When unit shipments are called from a terminal elevator, individual railcars will be accepted if they do not grade more than one grade below the weighted average grade and no lower than the lowest grade warehouse receipt.

CCC may reject shipments of grain loaded out of terminal elevators if:

1. the quality is lower than the weighted average quality or specific quality called for even though it meets the specific grade,
2. if it does not meet the unit shipment requirement, or
3. if it is not fairly representative of the quality ordered.

At country elevators, the warehouse operator must load a grade and quality that is fairly representative of the quality described by warehouse receipts. Unit shipments can be loaded from country elevators under the terms spelled out for terminal elevators when that is agreeable to the warehouse and CCC. On grain delivered from country elevators, the grain may be rejected if it does not meet the requirements specified in the loading order. CCC, however, will not reject individual railcars, except those grading sample grade, in a unit shipment from country elevators as long as the whole shipment is fairly uniform in terms of the quality called for in the loading order.

Settlement for load out is based on the value of the grain delivered and the grain ordered shipped by CCC using premium and discount schedules established by the agency. On grain delivered from terminal elevators that is accepted by CCC, settlement will be based on the value of the net deficiencies for all grain in the loading order. No discounts will be applied on unit shipments if the quality in all railcars equals the weighted average quality called for in the loading order. The warehouse operator must pay CCC for the value of underdeliveries in quality, but CCC will not pay for the value of overdeliveries. This is not the case for grain shipped from country elevators, as CCC will pay for the value of their overdeliveries.

When grain is rejected at terminal elevators, the warehouse will not be given credit for loading out that quantity. The rejected grain must be replaced even though additional grain must be obtained to meet the loading order issued by CCC. The agency can accept rejected grain if agreement is reached between both parties on a discount prior to CCC's authorization to ship.

At country elevators, the warehouse operator replaces the rejected grain at CCC's option. If rejected grain is not replaced, however, CCC sells it for their account. In determining values for grain shipped from country elevators, special provisions have been included for sample grade shipments not required by the loading order and a 10 cents/bushel charge is included for rejected grain that is not replaced.

The differences in CCC rules as they pertain to country versus terminal elevators creates some unusual problems for grain quality. The fact that CCC does not apply the same rules is a negative influence on the quality of CCC grain. Given that CCC premiums and discounts do not always reflect the market, the possibility therefore exists for quality deterioration of grain stored by country elevators and to some degree by terminal elevators.

USDA publishes figures for State average UGSA handling and storage rates for country and terminal elevators. In Iowa, for example, country elevators handling corn charge on average 7.92 cents/bushel for handling inbound truck deliveries and 8.79 cents/bushel for outbound by rail. The average storage charge there is 37.74 cents/bushel. Based on these figures, a country elevator that takes in corn, holds it for 1 year, and then loads it out receives 54.45 cents/bushel for handling and storing.

The USDA premiums and discounts for corn do not completely reflect the market discount levels. For example, USDA for June, 1988 assessed a 1-cent discount for corn damaged between 5.0 and 6.0 percent. A 2-cent discount was assessed for every 1-percent increase above 6.1 percent. Yet, market discounts for corn arriving in Kansas City on June 15, 1988 were 3 cents per percentage point above 5.0 percent. Thus corn containing 7.4 percent damage is assessed a 9 cents/bushel discount by the market, but only 5 cents/bushel by CCC.

All these considerations—the fact that CCC accepts grain below the quality represented by warehouse receipts, the costs of maintaining quality while in storage, the revenue received from handling and storage, and the less-than-market discounts that are applied—combine to create a situation in which the benefits of maintaining quality must be weighed against the economic benefits of delivering grain of poorer quality than indicated on warehouse receipts. Furthermore, the economics of this situation are more dynamic at country than at terminal elevators.

As noted, grain shipped from country elevators can be rejected if it does not meet the quality specified in the loading order, but country elevators do not have to replace the grain, in contrast to terminal elevators. When country elevators request unit shipments, the quality of individual railcars shipped as part of a unit will not be discounted as long as the average for the unit is fairly representative of the quality ordered. For unit shipments from terminal elevators, on the other hand, individual railcars are discounted. CCC policies therefore allow movement from country to terminal elevators of grain that is inferior in quality to what must be shipped from the terminal elevators, placing more responsibility on them to maintain quality.

Impacts of Markets, Farm Programs, and Technology on Quality

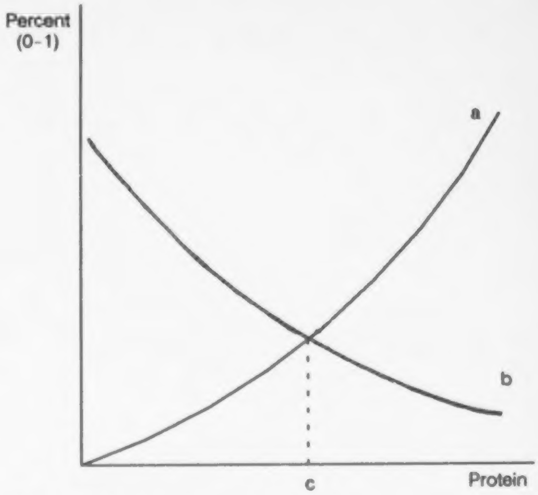
Agronomic practices and variety choice influence both the quantity and quality of production despite the uncertainties of biological processes. For example, the physical relationship between fertilizer and yield is well known, and there is some evidence that producers adjust yields in response to changing economic conditions. It is also plausible that quality characteristics adjust with changing economic and technological conditions. Changes in farm programs and market prices influence producer decisionmaking regarding yield versus quality. This section examines the extent of and potential for adjustments in quality content (via wheat protein) in reaction to economic variables.

The trade-offs governing yield and protein choices are somewhat imprecise biological relationships. In particular, yield and fertilizer are positively related because soil nutrients stimulate grain production. Also, yield and protein are inversely related because varieties may be chosen with relatively high yield and low protein or vice versa.

Producers are faced with a conflict between incentives and trade-offs, or between improving quality and reducing production. Production on a given parcel of land can be expanded either through more intensive farming practices or through reduction in crop quality. Resolution of these alternatives requires evaluation of contributions to profits by small changes in fertilizer and protein content. The profit contribution of a 1-point increase in protein consists of an increase in revenue due to the higher price and a decrease in revenue due to reduced yields. Profits can no longer be increased when the revenue gain from increased yield and the loss from reduced protein offset each other.

The functions influencing the producer's choice of protein level are illustrated in figure 9-2. The yield loss function is upward sloping, reflecting the reduced yields that accompany increases in protein. The shape of the percentage price gain function depends on the characteristics of the protein premium schedule. For demonstration purposes, it is a downward sloping function of protein content. However, it could be flat, which would imply the percentage price gain is constant across protein levels. The protein level that would maximize producer profits occurs where the percentage price gain and yield loss are equal. From the producer's perspective, this would be the most desirable protein level.

Figure 9-2.—Producers' Protein Choice for Wheat



a: Percent yield loss from higher protein

b: Percent price gain from a protein increase

c: Protein level that would maximize profits

SOURCE: Office of Technology Assessment, 1989

Thus, the producer's choice between expanding yield or protein entails evaluation of the trade-off of the economic returns associated with each alternative. As protein premiums change (e.g., due to a change in the market), the percentage price gain function (b) shifts, resulting in a different optimal protein level. Similarly, if target prices increase, at a given protein premium level in cents/bushel, the protein premium as a percent of target price diminishes, resulting in a reduction in the desired protein level. Likewise, as technology changes, the yield loss function would change, also resulting in a different desired protein level.

This conceptual framework suggests that producers can and do respond to protein premiums in their production decisions. An analysis of the extent to which producers have responded to changes in the market in variety choice and therefore protein levels in Kansas and North Dakota showed that protein levels have been decreasing in Kansas since 1978. Protein levels in North Dakota have been more variable, with a reduction from 1979 to 1985, followed by a slight increase in 1986 (4).

This study found overall only a small and occasional protein response to market incentives. In North Dakota, a change in the protein premium from historical minimum to maximum resulted in a 0.3 percent change in the average protein content. There is no evidence of any protein response in Kansas. Both States registered a long-term downward trend in protein level. One explanation is that in both cases, but especially Kansas, only a narrow range of protein choices is available from plant breeders, thereby limiting producers' ability to respond to economic variables (4).

A decline in protein content of 0.2 to 0.5 percent has occurred in Kansas and North Dakota during the last 20 years (4). This decline coincides with the adoption of new generations of technology; semidwarf varieties released since the 1970s have included varieties with lower protein levels than those previously available. Producers' choices among varieties include several factors in addition to protein content, such as yield advantage and disease resistance, that may be the primary influences on seed selection. Decisions about yield advantage and disease resistance may have indications for protein levels, but it does not appear that protein incentives have a strong influence on the average protein content of the Great Plains wheat crop.

FINDINGS AND CONCLUSIONS

Farm programs have played an important role in U.S. agriculture. Because they send incentives throughout the system, they have the potential to affect quality. Two farm program provisions are generally applicable: the loan rate program and its associated premiums and discounts for deviations from a specified quality, and the target price/deficiency payment program, which bases payments on yield. To the extent that yield and quality are inversely related, incentives to increase yield put pressure on producers to reduce quality indirectly. Analysis of these two aspects of farm programs resulted in the following findings.

- The administration of loan rate values for wheat has changed over time. In the 1960s two additional premiums/discounts for quality were available in addition to those for grade: one based on sedimentation tests and another for variety discounts. These were discontinued in the early 1970s.
- Substantial differences exist between loan rate premiums and discounts relative to those of the market. The spread of premiums and discounts for protein has nearly always been less than that for market premiums/discounts, and this difference has been increasing in recent years. The signals transmitted via the loan rate thus do not provide incentives for quality improvement and, because of these spreads, inferior quality wheat will have a tendency to go to the loan program.
- There is a distinct trade-off in production between yield and protein. In recent years this trade-off has been increasing, suggesting the opportunity costs of maintaining a certain protein level in terms of yield foregone is rising.
- The target price program provides an incentive to increase yields because of a higher price level per bushel. From a producer perspective the optimum protein level decreases as target prices increase. As target prices stimulate higher yields and therefore lowered protein levels, pressure

to increase protein premiums in the market has escalated due to a shortage of high protein wheat.

Given these findings, a combination of policy and institutional factors may inhibit producer response to quality incentives. Public information about the yield and quality consequences of particular variety selections is not generally available. Further, in some regions of the country the first point of receipt in the market channel typically does not apply to individual producers premiums and discounts for quality. And finally, the range of protein or quality choices available to producers from the plant breeders is small and may preclude adjustment.

Farm programs potentially have important impacts on quality in commodities such as wheat, corn, and soybeans in which the loan rate program is an important feature and where trade-offs exist between yield and a major quality factor such as protein. When the loan rate program is less than market premiums and discounts, it results in distortions. The most important one is that the incidence of inferior quality is not reduced. Given the amount of carryover storage of grain in the United States between crop years compared with other exporting countries, inferior quality grain is distributed over several subsequent years.

The target price program has longer term impacts. Incentives are transmitted throughout the production sector to increase yields. The transmission of signals from producers to plant breeders and ultimately to variety development is a long, dynamic process. The target price program causes underlying pressure for reduced protein levels in the market and thus fundamental pressure on protein premiums. There has been little response in the past to variability in protein premiums. This could be due in part to constraints of technology and variety development, and in part to release programs that have been given persistent signals over the years for increased yield.

Results of this analysis of farm programs were presented in testimony before the Senate Committee on Agriculture, Nutrition and Forestry and the House Agriculture Committee. Congress then amended the U.S. Grain Standards Act in Public Law 100-518 to direct the Secretary of Agriculture to establish a pilot project for the 1989 wheat, soybeans, and feed grains crops to determine a method of requiring the Commodity Credit Corporation to determine a schedule of premiums and discounts on grain offered as loan so as to encourage the marketing of high-quality grain.

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Chapter 10

Comparison of Technologies and Policies Affecting Grain Quality in Major Grain-Exporting Countries

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Chapter 10

Comparison of Technologies and Policies Affecting Grain Quality in Major Grain-Exporting Countries

This chapter focuses on the grain systems of the other major exporters—Argentina, Brazil, Canada, France, and Australia—in order to understand better their grain systems as they relate to quality and to consider adopting some aspects of those systems.

Observed differences among countries are important because the differing strategies influence incentives and the quality of the final product. A comparison of the major technologies, market channels, pricing strategies, and grading practices in each country provides the background for a comparison and analysis of the quality delivered into the domestic and export markets of each. Little published information is available about the grain systems of the other countries, especially with regard to technologies, institutions, and policies affecting quality; Canada is a major exception. To provide the documentation needed to prepare this chapter, OTA formed study teams to travel to each country except Canada to gather needed information. The study teams arrived during the harvest to observe the system at work. Information was gathered via numerous interviews with producers, handlers, processors, exporters, grain inspectors, plant breeders, researchers, and government officials. Detailed reports on each country are found in a second report in this assessment, *Grain Quality in International Trade: A Comparison of Major U.S. Competitors*.

This chapter looks at the technologies, handling practices, institutions, and government policies that affect grain quality in each country and compares them in each case with the U.S. system. The technologies are basically the same, with some minor variations. But major differences exist in the use of technologies, in institutions established, and in policies that affect grain quality.

PRODUCTION TECHNOLOGIES AND PRACTICES

The major grains—corn, wheat, and soybeans—are grown under various soil and climate conditions and differing cultural practices (table 10-1). Most of the best soil conditions in each country are used to produce these grains. Cultural practices differ, depending on site conditions. All the countries, however, use mechanized soil preparation, seeding, and cultivation. Differences exist in the degree to which fertilizer, insecticides, and herbicides are used. France is the most intensive user of fertilizer, and this is reflected in its tremendous increase in wheat yield over the past 10 years. The high yields and fertilizer rates are primarily a response to economic incentives provided by the Common Agricultural Policy of the European Community (EC).

Harvesting technologies are similar in all countries. The only difference of note is in Australia, where a second screen may be used on the combine to filter nonmillable materials from the wheat. Farmers have the incentive to use this practice because they do not want their wheat rejected at the country terminal. No such incentive exists in the United States at the point of first receipt.

Major differences among countries can be found in the capacity for and reliance on on-farm storage. The United States has the capacity

Table 10-1.—Comparison of Production Technologies of Major Grain-Exporting Countries

Activity	United States	Argentina	Brazil	France	Canada	Australia
Soils and topography	Major production areas are on stable soils. Low erosion. Fertility stabilized. Soybeans usually incorporated in a rotation with corn or other crops. Winter wheat grown under dry land conditions.	Flat, fertile soils in the corn belt. Rolling land farther south in wheat and sorghum area. Long rotations including legume pasture. Soybeans and wheat are often double-cropped.	Expanding production on newly cleared soils. Long slopes and year-round erosion and leaching create more problems of maintaining fertility. Extensive terracing required. Continuous soybeans not unusual in Parana and Mato Grosso do Sul.	Major production areas for wheat located north and southwest of Paris on stable, low erosion soils. Rolling land farther south in corn-producing area.	Wheat grown for export in four soil zones in western Canada. All wheat grown under dry-land conditions.	Major wheat production areas include south and east coast, and western Australia. Rolling, dry land. Extended rotations with clover.
Cultural practices	Fertilizer, insecticide, and herbicide used as needed. Mechanized soil preparation, seeding and cultivation.	Limited use of fertilizer on corn, increasing use on wheat. Limited use of herbicides and insecticides. Mechanized tillage seeding and cultivation.	Fertilizer, insecticide, and herbicide used as needed. Mechanized soil preparation, seeding and cultivation.	High use of fertilizer, insecticide, and herbicides. Mechanized soil preparation, seeding, and cultivation.	Fertilizer, insecticide, and herbicide used as needed. Mechanized soil preparation, seeding, and cultivation.	Phosphatic fertilizers, insecticides, and herbicides used as needed. Mechanized soil preparation.
Harvesting	Self-propelled combines. Wheat crop in Northern plains is swathed before harvest.	Self-propelled combines.	Self-propelled combines.	Self-propelled combines.	Self-propelled combines. Wheat crop is swathed before harvest.	Self-propelled combines.
On-farm storage	On-farm storage available for about 50 percent of corn and soybeans.	Only 5 to 10 percent stored on farms. Only very large farms use on-farm storage.	Virtually no on-farm storage.	Very little stored on farms.	On-farm storage for the majority of wheat.	Virtually no on-farm storage.

SOURCE: Office of Technology Assessment, 1989.

to store about half the on-farm grain produced. In Argentina, Brazil, France, and Australia, on-farm storage capacity is small. Quality control is the major reason given by Government agencies for discouraging on-farm storage. In Australia, for example, the Wheat Board emphasizes cleanliness and insect control in wheat. It is their belief that storage provided off-farm by handlers, more experienced with and knowledgeable about the procedure, results in fewer quality problems. Greater use of on-farm storage would, according to the Australians, increase infestation and/or pesticide residue. An important fundamental of grain marketing in many countries is that the establishment of stringent requirements at the first point of receipt precludes problems downstream in the marketing system. Minimal on-farm storage is an important component of that concept.

HANDLING TECHNOLOGIES AND PRACTICES AT FIRST POINT OF RECEIPT

Handling technologies and practices at first point of receipt include the receiving, drying, cleaning, storage, conveying, and transporting of grain (table 10-2). Few differences exist among the countries in how grain is received. Country elevators basically accept grain in either farm wagons or trucks. Some countries (the United States) are more mechanized than others (Brazil). But the differences are minor and inconsequential as far as quality is concerned.

Drying

The same type of drying technology basically is used in all countries. Most corn needs to be dried everywhere. Soybeans in Brazil are usually dried, but in Argentina and the United States this is done to a lesser extent. High-temperature dryers, either gas- or oil-fired, are used for the most part. Wheat drying varies by country. France harvests wheat above 15 percent moisture and dries it for safe storage. Australia, on the other hand, rarely needs to dry wheat because of the country's dry climate.

Cleaning

Cleaning practices differ by country. In the United States and Canada, grain is generally not cleaned at the first point of receipt. In Argentina, Brazil, and France, economic incentives exist to clean grain at this level in the market channel. In fact, in France it is not uncommon for wheat to be cleaned going in and coming out of country elevators. Not cleaning grain at the first point of receipt ensures that foreign material remains, adding to the cost of transporting and handling grain throughout the rest of the marketing channel.

Storage and Handling

The technologies for storage and grain handling are the same for all countries. Differences arise in the configuration of storage units and in the speed of handling equipment. In some countries, such as the United States, vertical or upright storage facilities predominate. Flat storage is most prevalent in Brazil. And in Australia, storage facilities vary by state.

Transportation to Ports

Rail and truck are the major modes for transporting grain to port facilities in most countries. The United States is an exception in that it also has major waterways for transport. Barge transportation is more cost-effective than truck and rail. From a quality viewpoint, however, it has potential problems. As discussed in chapter 7, moisture uniformity is important in maintaining quality. During shipment, moisture migration can be significant if grain is exposed to several outside temperature and humidity changes. Barges seem to be more susceptible to these factors than railcars. In addition, grain may need to be handled more at times because of barge movement, which increases the likelihood of damaging the kernel—especially for corn. The United States may have an advan-

Table 10-2.—Comparison of Handling Technologies and Practices at First Point of Receipt of Major Grain-Exporting Countries

Activity	United States	Argentina	Brazil	France	Canada	Australia
Receiving	Truck dumps and hoists for virtually all farm wagons and trucks.	Truck dumps and hoists at larger facilities. A few receiving stations lack hoists. Waiting lines are common at harvest.	Truck dumps and hoists at larger facilities. Many vehicles unloaded by hand.	Truck dumps and hoists for farm wagons and trucks.	Truck dumps and hoists for farm wagons and trucks.	Truck dumps and hoists for farm wagons and trucks.
Drying	The majority of corn is dried and stored on farms. Most of the corn delivered at harvest is dried by first handler in gas-fired dryers. Little drying of soybeans or wheat.	Majority of corn and some soybeans and wheat are dried in high-temperature dryers. Nearly all country elevators have dryers. Usually oil-fired.	Majority of soybeans dried. Wood and coal used for fuel.	Some drying of wheat if harvested above 15% moisture. Majority of corn dried with high- temperature dryers similar to those used in U.S.	The majority of wheat is dried and stored on farm. Propane dryers are most common.	Generally wheat does not need to be dried. No dryers at bulk handling authority (BHA) facilities.
Cleaning	Generally grain is not cleaned when it comes off the farm. It is placed in bins according to quality so that it can be blended with grains of different quality when loaded out.	Since there is a premium for No. 1 grain, most grain is cleaned to less than 1.0% foreign material.	Soybeans that exceed Brazilian export quality (foreign material 1.0%) are cleaned. Corn is cleaned to less than 1.0%.	Most wheat cleaned going into country elevator and some cleaned going out. Corn routinely cleaned because of broken kernels.	Very little cleaning done at this level of marketing system.	Generally wheat does not need to be cleaned. No cleaners at BHA facilities.
Storage	Flat and upright storage. Upright predominates.	Flat and upright storage. Determined by relative costs and handling requirements.	Flat and upright storage. Flat predominates.	Upright storage predominates. Grain often turned and sampled for end-use quality tests. Also use flat storage with numerous vertical bins.	Vertical cement bins; flat storage and steel tanks. Vertical predominates.	Upright, flat, and bunker. Predominance of any type varies by state.
Handling	Use augers, conveyors, belts, and vertical legs.	Use augers, conveyors, belts, and vertical legs.	Use augers, conveyors, belts, and vertical legs.	More use of chain conveyors than belts.	Use augers, conveyors, belts, and vertical legs.	Use augers, conveyors, belts, and vertical legs.
Transportation to ports	Trucks for short hauls. Rail and water for long distance.	Truck and rail choice determined by cost and shortage of rail service. Barge available for movement to Buenos Aires.	Truck predominates for all distances. Water available only in southern district moving beans to Rio Grande do Sul.	Grain predominantly transported by truck.	Grain predominantly moved by rail over long distances.	Most wheat is moved by rail, some by truck.

SOURCE: Office of Technology Assessment, 1989.

tage compared with other countries because barge transportation is more cost-effective than alternative modes of transportation. But from a quality standpoint, this may not be an advantage.

HANDLING TECHNOLOGIES AND PRACTICES AT EXPORT

Many of the handling technologies at the final point in the marketing channel are similar among the countries (table 10-3). But, as with the practices at first point of receipt, how they are used differs.

Storage

Storage technologies do not vary among the countries. The number of bins for segregating by quality does differ, however, as well as the speed of moving grain in and out of storage. The United States has the capacity to segregate grain into multiple bins for storage, which expedites blending. Other countries, such as Argentina and Brazil, have few bins into which grain can be segregated by quality.

Drying and Cleaning

No major differences exist in either technologies or practices of drying and cleaning grain at this point. As grain basically is dried and cleaned at the first point of receipt, there is little need for dryers or cleaners at export. The United States is somewhat of an exception because many export facilities receive grain directly from farmers. And grain must be conditioned for safe storage and handling. But in most other countries, such as Argentina and Australia, grain received at export has already been conditioned at the first point of receipt. A major exception is Canada, which cleans wheat at the port facility. However, Canada is presently studying this practice and the research indicates that cost savings exist in cleaning wheat at inland terminals versus at export. A basic marketing fundamental of most exporting countries is to condition grain at the first point of receipt and avoid problems and costs at later stages in the marketing channel.

Blending

Canada blends wheat to a degree at primary elevators but is limited to the extent it allows blending at export terminals. Other exporters blend grains only to a small degree, mainly because it is uniform upon receipt. The physical facilities in these countries have been constructed to limit blending of wide margins of quality. In contrast, grain moving through the marketing channel in the United States is not uniform. Blending is done across diverse qualities in an attempt to produce a uniform product for export.

INSTITUTIONS AND REGULATIONS AFFECTING GRAIN QUALITY

Although the technologies of producing, transporting, and handling grain do not differ significantly among exporters, the use of them does. And they differ to a large extent because of the varying institutions in each country. This section discusses the institutions and regulations important in influencing grain quality in these countries (table 10-4).

Seed Variety Control

The fundamental area for influencing quality is through incentives to plant breeders. All major grain-exporting countries except the United States have instituted formal mechanisms for controlling variety development and release. In France, Canada, and Australia, va-

Table 10-3.—Comparison of Handling Technologies and Practices at Export of Major Grain-Exporting Countries

Activity	United States	Argentina	Brazil	France	Canada	Australia
Storage	Vertical storage with multiple bins, high speed in and out. Segregated by quality to expedite blending at time of shipping.	Vertical silos predominate. Few bins for quality segregation.	Vertical and flat storage. Small number of bins limits segregation by quality.	Upright bins predominate, stored according to end-use qualities.	Vertical, cement bins predominate. Blending is very limited—grades must be kept separate.	Vertical storage segregated by quality.
Drying	Most export facilities have large drying capacity. Corn is often dried if received direct from farmer but soybeans and wheat are seldom dried.	Grain dried by first handler; dryers at export are seldom used.	Grain dried by first handler, dryers at export seldom used.	Very few export elevators have dryers; grain is conditioned by first handler.	Most export facilities have modest drying capacity.	No dryers at export facilities.
Cleaning ...	Most export facilities have capacity for cleaning. Grain (mostly corn) often cleaned prior to exporting.	Grain cleaned by first handler. Relatively small capacity cleaners.	Grain cleaned by first handler. Little or no cleaning capacity.	Most export elevators do not have cleaners; grain cleaned by first handler.	Most cleaning of wheat is done at this point in marketing system.	No cleaners at export facilities.
Blending ...	Normal practice. Economic incentive for blending of wide range of quality due to the extremes in quality of grain accepted into the system.	Limited blending because of uniform grain received and lack of physical facilities for blending.	Limited blending because of uniform grain received and lack of physical facilities for blending.	Some blending of wheat moving to export, but no incentive to blend wide margins of differing qualities.	Blending at primary elevators, but at export only 2% of higher grade can be a blend from a lower grade.	Limited blending at export but only for a few factors.

SOURCE: Office of Technology Assessment, 1989.

Table 10-4.—Comparison of Institutions and Regulations Affecting Grain Quality of Major Grain-Exporting Countries

Activity	United States	Argentina	Brazil	France	Canada	Australia
Seed variety control	No State or Federal control. Release of varieties influenced to some extent by land-grant universities. Largely the market determines adoption of varieties.	Committee of government and industry must approve agronomic properties. Quality factors of minor influence.	Committee with broad representation directs research and approves varieties. Quality is potential criterion but not currently effective.	Formal mechanism exists that regulates release of varieties based on agronomic and quality criteria.	Formal mechanism used to license new varieties. Agronomic and quality criteria given equal weight in testing new varieties.	Formal mechanism followed as a prerequisite for release of varieties. Quality and agronomic criteria are used.
Grain receival standards	None. All types of quality are accepted with appropriate discounts for low-quality grain.	Grain not meeting a specified minimum quality (Condition Camara) is rejected at first point of sale.	Soybeans not meeting a minimum quality are rejected at first point of sale.	Grain not meeting export contract specifications can be rejected by surveying company or receiving elevator.	Developed eight grades for CWRS to differentiate quality. Lowest grade goes to feed market.	Wheat must meet minimum quality standards. If not it is allocated to feed market.
Marketing by variety	No mechanism exists for variety identification.	Variety is not identified in marketing channel.	Variety is not identified in marketing channel.	Very common. Variety often specified in wheat contracts.	Licensed grain must be visually distinguishable.	Very common-use variety control scheme to facilitate segregation by classes.
Grain inspection authority	Federal Grain Inspection Service (FGIS), U.S. Department of Agriculture.	Junta Nacional de Granos—Government agency responsible for agriculture.	Private inspection agencies.	Private inspection agencies.	Canadian Grain Commission.	Export Inspection Service of Department of Primary Industry.
Grade standards	Official standards established by FGIS.	Official standards established by Junta.	Official standards are not used in export. Quality is based on Association Nacional dos Exportadores de Cereais contract.	No official standards. Only official quality criteria are requirements for intervention mechanism.	Grain standards established by Canadian Grain Commission.	Official standards established by Department of Primary Industry.

SOURCE: Office of Technology Assessment, 1989.

riety approval and release must take into account quality as well as agronomic criteria. And quality is given equal weight with agronomic criteria for approval of new varieties. Argentina and Brazil also have formal structures for release of new varieties, but currently give more weight to agronomic criteria than quality. Improving yields in these countries is more important than quality improvement at present. But the mechanism is in place to consider quality criteria when it becomes necessary. The United States stands alone as the only major grain exporter with no State or Federal Government involvement in release of new varieties. The U.S. market largely determines the varieties adopted.

Grain Receival Standards

Another common characteristic of most exporters concerns receival standards. All countries except the United States have minimum quality standards that must be met for grain to be accepted at the first point of receipt. Grain that does not meet these standards is rejected, and is diverted to the feed market in most countries. However, the United States accepts all qualities of grain into the market channel, with appropriate discounts for low-quality grain. Uniformity of quality is more difficult to attain without minimum receival standards and provides the incentive for blending discussed earlier.

Marketing by Variety

In some countries grain is identified in the marketplace by variety, which is used as a proxy for end-use value. France and Australia are the countries that use variety in the marketing of wheat most extensively. Farmers in these countries must declare in an affidavit the variety of wheat marketed at the first point of receipt. France and Australia use variety to facilitate the segregation of wheat by class. The United States has no mechanism for variety identification.

Grain Inspection Authority and Grade Standards

Most of the countries have official standards established by the Government and the inspection of grain is conducted by a Government agency. Brazil and France are major exceptions. France has no official standards or Government involvement in grain inspection. Quality standards have been established by state and national agencies in Brazil but domestic and export trade is based on a contract under the Association Nacional dos Exportadores de Cereais. In France the quality requirements for the EC intervention mechanism provide the minimum standards. Private agencies in both countries provide grain inspection services.

GOVERNMENT POLICIES AFFECTING GRAIN QUALITY

As discussed in previous chapters, government policies on agriculture play a major role in determining the importance of quality in the market. These policies differ considerably among the grain exporting countries. The most important policies affecting quality include price policy and farm storage (table 10-5).

Price Policy

Price policy and the signals it sends through the market vary among the exporters. At one extreme is the United States. Through its loan program, premiums and discounts are established for major grains, but as discussed earlier the level of the premiums and discounts has not reflected market conditions since the 1960s. In addition, economic analysis clearly shows that the price signals of the loan program favor yield over quality (see ch. 9). At the other extreme, the Argentine Government provides a minimum price and establishes premiums for high-quality grain. The grain industry of Argentina produces and conditions grain for the best quality grade. Brazil, France, Canada, and Australia also have Government price policies

Table 10.5.—Comparison of Government Policies Affecting Grain Quality of Major Grain-Exporting Countries

Policy	United States	Argentina	Brazil	France	Canada	Australia
Price	Loan rate is principal price policy. Includes premiums and discounts for major grains but has not been responsive to market conditions.	Government establishes minimum prices for farmers and exporters. Government also establishes premiums for high-quality grain.	Government establishes a minimum price prior to planting. It is adjusted during the crop year to account for inflation and political pressure.	Key policy is European Community intervention price, which includes premiums and discounts for quality factors. Lower qualities of wheat equated to feed values.	Initial producer price is the principal price policy. Separate prices established for each grade of grain. Lower qualities of wheat equated to feed values.	Guaranteed minimum price (GMP) is key price policy. It is established by class and provides differentials for quality. Lower qualities of wheat equated to feed values.
Farm Storage	Farm policy in past decade has encouraged extensive on-farm storage and inter-year storage.	Government policy through pricing does not encourage on-farm or inter-year storage.	No incentive for farmers to store on farm.	Farm policy through the Common Agricultural Policy (CAP) has not encouraged development of extensive on-farm storage. Also relatively limited inter-year storage due to CAP.	Producer deliveries are regulated to primary elevators via quotas. On-farm storage is substantial.	Use of GMP provides no incentive for delivery in post-harvest period, leading to minimal use of on-farm storage.

SOURCE: Office of Technology Assessment, 1989.

that include quality incentives for the grain industry.

Farm Storage

Government policies also influence the amount of on-farm storage. Most countries do not have policies that encourage on-farm storage and/or inter-year storage. The exceptions—Canada and the United States—do have incentives for such storage. But there are differences. Canada establishes quotas to regulate farmer deliveries to primary elevators. On-farm storage therefore is a requirement. However, grain is moved through the system during the marketing year. In contrast, the United States has encouraged extensive on-farm storage through the loan program and farmers' reserve. In addition, it is unusual to market the entire crop in any one year. Indeed, it is more common for grain to be stored on-farm for more than a year, creating more potential for quality problems to develop.

COMPARISON OF U.S. INSTITUTIONS, POLICIES, AND TECHNOLOGIES WITH THOSE OF OTHER GRAIN-EXPORTING COUNTRIES

This final section focuses on the major differences between the U.S. grain system and that of other countries. No one system is ideal. Only by understanding how the U.S. system compares with other exporters is it possible to begin considering potential changes here to enhance quality.

As noted, from a technological standpoint few differences exist among the countries. The major differences revolve around exporters' institutions and policies regarding grain quality which influence how these technologies are applied.

Policy

The United States has a farm price policy that affects grain quality in at least two ways: it provides economic incentive for yield v. quality, and it provides economic incentive for on-farm storage. This stands in contrast to other countries. As indicated in chapter 9, premiums and discounts are not reflective of market conditions. Even with price differentials, the economic incentive is for yield, and low-quality grain moves into government loan storage program.

On-farm storage is a unique characteristic of the U.S. and Canadian systems. The other countries do not provide incentives for on-farm storage. This allows grain to enter the market channel with a better likelihood that it will be handled and stored with a minimum of quality deterioration. In fact, Australia has built its entire system around the concept of controlling the grain as soon as possible off the farm to maintain quality. However, another distinguishing characteristic of the U.S. system is that grain has the potential for carry-over from one year to the next, sometimes for as long as 3 to 4 years. Other countries do not have the storage capacity for such carry-over. This forces the marketing of most grain within a year of production and nearly eliminates any problem regarding quality with inter-year storage.

Institutions

The U.S. grain system has three major institutional characteristics regarding quality:

1. lack of a seed variety development and release program,
2. lack of a variety identification mechanism, and
3. no minimum receival standards for grain.

These major, fundamental differences from other grain-exporting countries have a considerable influence on quality.

Seed Variety Development and Release

Chapter 6 discussed in detail the plant breeding programs for corn, soybeans, and wheat in the public and private sector of the United States. There is at best a loose mechanism for the development and release of new varieties. Committees, particularly at land-grant schools, can evaluate new varieties. But there is no State or Federal involvement in any formal way. Government basically gives no formal signal as to the criteria for release. The signal comes indirectly through the price support program, which emphasizes yield and the agronomic characteristics to achieve higher yields. In contrast, Governments of other countries have formal input into the criteria for development and release and they formally approve new varieties. Quality is a major criteria they consider in the release of new varieties, at least for wheat.

Variety Identification

In some countries, mainly France and Australia, not only is variety controlled for use by farmers but variety is also important as a proxy for end-use value. An important feature of the French marketing system is that variety is often a contract term. In practice, varieties are specified as either an individual variety, a category of varieties, or excluded varieties. Given that varieties are in general not usually distinguishable by visual inspection, various mechanisms are used at the first point of receipt to assure the integrity of variety specification. First, in most cases, the cooperative receiving the grain in France has sold the seed to the producer and knows its variety. Second, producers must declare the variety at the time of sale via an affidavit. Third, the buyer can perform a rudimentary testing procedure or request an electrophoresis test from a laboratory to verify the variety. By knowing the varieties at the time of receipt, country elevators are capable of binning by varieties, or categories of varieties, and of selling on that basis. The United States has no mechanism for variety identification and instead relies on grade structure for segregating quality, which is becoming more difficult as new varieties, especially of wheat, are not easily distinguishable.

Grain Receival Standards

As noted earlier, the United States is the only country that does not have minimal receival standards for grain. Producers can deliver any quality of grain and it will be accepted with appropriate discounts. Other countries would not allow this. Grain that does not meet the established minimum quality may be rejected at the first point of sale. Keeping low-quality grain out of the market channel eliminates most quality problems at the export elevator and reduces the opportunity for blending diverse qualities. Once low-quality grain is in the system it is much more difficult to keep it segregated from higher quality grain or to keep it from being blended with such quality grain destined for export.

Technologies and Grain-Handling Practices

The policies and institutional structure of the U.S. grain system provide the framework for various grain-handling practices. The technologies for producing and handling are quite similar everywhere. The main difference is that the United States is slightly more efficient in their use. Differences do exist, however, as to when the technologies are used in the marketing channel.

A case in point is cleaning. Most countries except the United States clean grain at the first point of receipt. Canada and Australia are two exceptions, but for different reasons. Canada, however, is studying the economic feasibility of cleaning grain in the country versus at export and will probably change. Australia does not clean because unlike in the United States, the farmers deliver grain that does not need to be cleaned. Basically, no economic incentive exists to clean grain at the first point of receipt in the United States.

The other major handling practice in which the United States differs from all other exporters is blending. Blending of grain over wide margins of quality to create a uniform product for sale is necessitated by the lack of any minimum receival standards. Blending does exist elsewhere, but not to the same extent. Blending in other countries is done over narrow ranges in quality. These countries basically have a uniform quality moving through the system at any point in time. The U.S. system lacks uniformity in quality throughout the market channel. When grain reaches export, blending is used in an attempt to produce a uniform quality meeting the buyer's specifications. The OTA survey of foreign and domestic buyers of U.S. grain clearly indicated that lack of uniformity between shipments is buyers' biggest complaint (see ch. 4).

Chapter 11

Policy Options for Enhancing Grain Quality

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Chapter 11

Policy Options for Enhancing Grain Quality

Grain quality is influenced by numerous highly interdependent features of the U.S. grain marketing system, including variety development, production, handling, and merchandising. Trade throughout the system is facilitated by a set of grain standards, and those involved in the market channel respond to incentives and disincentives established for quality characteristics. Much of the policy debate on U.S. grain quality has focused on grain standards, but they are only one of many policy and regulatory alternatives that influence quality. Quality must be thus viewed as part of an integrated system focused on delivering the optimum quality for each domestic and foreign user. The interdependence of the system means that more policy alternatives exist than are traditionally considered and that changes in any one part of the system will have impacts elsewhere.

The first section of this chapter on policy alternatives briefly describes the problems identified during this assessment. The second section discusses the interdependence of the grain system, and identifies a number of policy alternatives and their implications.

SCOPE AND DIMENSIONS OF PROBLEMS

The system for marketing grain in the United States has a number of important characteristics that affect quality. The handling (including export) and transport industries are highly competitive, with relatively limited government intervention. One important principle throughout the system is decisionmaker sovereignty: Producers plant varieties that are perceived to be in their best interest; users (domestic and importers) specify and purchase qualities, given a range of alternatives and prices, that are in their interest; handlers and exporters condition and move grain in their own interest. Each decision assumes the sovereignty of the individual decisionmaker and is based on incentives and disincentives reflected in market premiums and discounts for quality characteristics.

Fundamental Advantages of the U.S. Marketing System

In comparing the grain systems of other exporting countries (see ch. 10), several fundamental advantages of the U.S. marketing system are clear in addition to those discussed in chapter 2. At the risk of simplification and with the intent of being general, five broad advantages are identified that encompass several others.

1. Efficiency

The U.S. marketing system performs a number of complex functions—assembling, handling, conditioning, and allocating different qualities to domestic buyers in many locations for export from a multitude of ports. Indeed, the quantity of grain produced, the many differences in qualities produced at different locations, and wide-ranging locations of end-users and ports all mean that the U.S. marketing system is more complex and performs more challenging functions than the systems of any other exporter. Yet the grain handling and transport system is more efficient than that of nearly all other countries. Efficiency is used here in the context of cost (or inputs used) in performing the necessary marketing activities. Efficiency and competition assure lower marketing margins and higher prices to producers.

2. Productivity Growth

Plant breeding in the United States is relatively unfettered, compared with other countries, in terms of regulations over variety development and release. Success of a variety is ultimately determined by the market for seed stocks. Producers make choices in response to market incentives. Where comparisons are appropriate (e.g., in wheat), productivity growth as measured by yield exceeds that of most other exporting countries, with the exception of France. Productivity differences are affected by a multitude of factors including environment, soils, other inputs, relative prices, institutions, and policies. Thus it is impossible to attribute yield differences to the institutional environment affecting varieties, but growth rates are influenced by variety release procedures.

3. A Wide Range of Qualities

Compared with other countries, a wider range of intrinsic qualities is available in the United States, particularly for wheat. This is obvious given the class differences in wheat, which are facilitated by production regions of differing environments and soils. There is also a wider range of physical and sanitary quality in the United States. Although this is an advantage in that more alternatives are available to buyers, some at lower costs, it may be viewed as a disadvantage in the sense that "reputation" is affected. The uniformity problem discussed later in this chapter is a direct result of the multitude of qualities available. In addition, given the lack of controls in the system, the multitude of qualities requires expertise on the part of importers if they are to fully benefit from the wide range.

4. Grading and Inspection System

The grading and inspection system in the United States provides grade determination by an independent government agency (i.e., one not having financial stakes in the transaction). The factors and limits in factors in the grade standards are relatively stable across crop years—e.g., No. 2 corn does not change from year to year. Similarly, the definition of No. 2 Hard Red Winter wheat does not change in the grain standards, although intrinsic differences not measured in the standards may change. This is not necessarily the case in exports from other countries. Major changes cannot be implemented in less than a year after they are mandated. Some other exporting countries adjust factor limits with each crop year.

5. Market-Determined Premiums and Discounts

In all countries, premiums and discounts and/or regulations are used to provide quality incentives to market participants. Those in the United States act through the interaction of the supply and demand for measurable quality characteristics, i.e., the market for quality characteristics. Consequently, values of quality characteristics in the United States perhaps reflect the true values better than do the premiums and discounts administered by government agencies of several other exporters, with the notable exception of France. Efficient determination of these price differentials is important because these essentially allocate grain across end-users and provide signals throughout the production and marketing system. Through these differentials the system responds to needs of the market.

Problem Areas

This assessment identified a number of important general problem areas that must be considered when discussing policy alternatives.

Genetics and Variety Release

An inverse genetic relation often exists between yield and important intrinsic quality characteristics in each of the major grains. In the case of wheat, this relationship is well recognized between yields and protein quantity, and a similar situation exists in corn and soybeans. Breeding programs generally aim to improve yield and disease resistance and satisfy apparently desirable intrinsic quality goals. In the case of corn, breeders have always sought to increase yield and improve harvestability, with intrinsic quality not being a priority. In many cases yield is emphasized because intrinsic quality characteristics, though important, are not measured in the market. Incentives therefore are not transmitted through the market as readily as those associated with agronomic characteristics such as yield, disease resistance, and harvestability.

Individual breeders or their institutions exercise tremendous discretion regarding release of varieties. However, this discretion is tempered by the market system, which determines the success of any release. Market efficiency requires measurement of relevant intrinsic quality characteristics, which is absent in many cases. For example, a variety with lower yield but an improved intrinsic characteristic (e.g., bake test) that cannot be measured in the marketing system would fail to survive in the seed market. Current variety release procedures are not applied uniformly across States (or firms, in the case of private breeding) or over time. No effective national policy on variety release assures uniformity in application of release criteria. In the case of wheat, in which public breeding is more important, the State Agricultural Experiment Stations maintain variety release procedures that are in turn guided by the Experiment Station Committee on Organization and Policy. Individual States may and do vary from this policy. Ultimately a particular class of wheat, corn, or soybeans produced in different parts of the Nation may differ in intrinsic quality.

Grain Standards

The current U.S. grain standards have four important limitations:

1. they create incentives for practices inconsistent with good management and efficiency;
2. they fail to identify many of the characteristics related to value in use;
3. they fail to reward producers and handlers for improved drying, harvesting, handling, and variety selection; and
4. grade limitations on many factors are arbitrary, do not always reflect real differences in value, and in some cases are not consistent with statistical principles.

No standard can be perfect, and any revisions must consider trade-offs. To move toward an ideal system, changes in grain standards should focus on grade-determining factors, non-grade-determining factors, and definition and measurement technology for official criteria. (Each of these, as well as their interrelationship, is described in ch. 8.) Such a system would entail minimal interference yet allow for improved efficiency in the market.

Buyers' Attitudes Toward Quality

As part of this assessment an extensive survey was conducted of grain buyers' attitudes toward quality, grain standards, and merchandising practices. Several general findings are important. First, all buyers, but particularly those outside the United States, indicated that uniformity between shipments was a problem (i.e., uniformity in intrinsic quality). As processing technologies become more sophisticated, uniformity will become more important. Second, in the case of wheat, nearly half the foreign buyers relied on imports because of the inadequate quality of domestically produced wheat; wheat from all other exporters was preferred at equal prices to similar types of U.S. wheat. Third, buyers thought that the standards for wheat, corn, and soybeans were inadequate and did not accurately describe the underlying shipment. Fourth, no one set of quality attributes meets the demands for each product of the grain system.

U.S. Farm Policy

Two important features of U.S. farm policies have an impact on several aspects of quality. Because of the inverse relation between yield and intrinsic quality, the target price program in wheat (and to a lesser, or less identifiable, extent in feed grains) has a negative long-term impact on intrinsic quality in conjunction with price differentials less than those of the market. As the target price typically exceeds the market price, farmers have an incentive to expand yields. Impacts vary by grain and region, depending on the extent of the inverse relation between yield and intrinsic quality. The effect had been exacerbated by previous farm bills that used different methods of determining yield. The total impact in the case of wheat has been to force market premiums for wheat protein to relatively high levels in order to neutralize producers' decisions.

Administration of the loan rate program also has an impact on intrinsic quality, as well as on physical and sanitary quality. In particular, the market for measurable quality characteristics is distorted because premiums and discounts on forfeited grains, particularly wheat, are less than those determined in the market. Poorer quality grain is put under storage, and market differentials are depressed.

Changing Role of Demand

The international wheat market is more differentiated today than at any time in the past 25 years, a reflection of the divergent nature of end use and the intensity of exporter competition. Unique preferences were identified in the OTA survey across types of wheat, suggesting homogenization would be counterproductive. In general, demand has shifted toward higher protein and soft wheats. An important related problem in international wheat competition is that the market premium for protein has increased substantially in recent years. This has caused a number of difficulties in the marketing system (due to measurement and uniformity problems), and has affected international competition. Specialization and sophistication in corn and soybean processing have also opened new markets with more exacting quality requirements.

Competitors' Policies

Major differences exist in the institutions, policies, and trading practices in other grain exporters marketing systems. The extent of market intervention varies from highly regulated throughout (e.g., Australia and Canada) to partial or no regulation. Differences also exist in procedures for variety development and release, the use of variety identification in the marketing system, and the use of grain receival standards. In addition, a number of countries address grain quality problems as part of their effective agricultural policy variables. At least for wheat exporters, the quality at first point of sale is more extensively controlled than in the United States. The wheat from these countries is now probably preferred over U.S. wheats at the same price due to these mechanisms.

POLICY OPTIONS

A number of policy alternatives are available to address these problems. Their overall purpose is to create a policy environment that enhances grain quality. As discussed, the U.S. grain production and marketing system is highly interdependent, and policies focused on any one sector affect other sectors to differing extents. This section analyzes a number of specific policy alternatives in the context of the interdependence of the system. Alternatives can range from regulation to reliance on the market.

Market Solutions and Regulations

A properly functioning market system can solve many of the apparent problems in quality. To do so, however, appropriate information must be provided so that relevant incentives and disincentives can develop. A fundamental policy alternative is to create an environment that would improve the ability of the market to identify and allocate grains of differing qualities to the highest value use.

The market for different quality characteristics drives the multitude of individual decisions that affect quality from seed to end use. Through the market for quality characteristics, price differentials develop that provide incentives and disincentives for participants throughout the system. An important aspect of this market is that premiums and discounts, and therefore incentives and disincentives, develop for important measured characteristics. Bargaining and contracting for quality specifications occurs throughout the system, explicitly or implicitly, between buyers and sellers. Premiums and discounts are built into contracts, reflecting marginal valuations of the participants, and limits are frequently included beyond which the shipment would be unacceptable. Thus, fairly fluid implicit markets (i.e., premiums and discounts) exist for characteristics such as protein quantity in wheat; damaged kernels, dockage, moisture and broken corn/foreign material in corn; and damaged kernels in soybeans. These reflect market-determined values of these characteristics. Less is known about other unmeasured quality characteristics (intrinsic or otherwise), and the market is not necessarily capable of reflecting end values in underlying prices.

The important point is how the market works, through premiums and discounts, and that it works efficiently only for easily "measurable" (and verifiable) characteristics. This poses the fundamental problem in that not all items of importance in end use are easily measurable in the marketing system. In fact, as discussed, few intrinsic characteristics are included in the standards. Instead, proxies are often used that are less than precise. Domestic buyers can make purchases by location, or by region, an alternative not easily exercised by foreign buyers. The problem is lessened somewhat to the extent that variety release procedures use quality tests that are important but that are not used in the marketing system.

An alternative to market solutions would be to impose regulations, which could very well solve many of the perceived quality problems. But regulations impose costs on the system, which due to the competitiveness of the marketing system are passed back to producers in the form of lower prices and/or to users in the form of higher prices. Higher costs associated with regulation would not be absorbed by the handling system. In other words, regulations impose costs on the system that buyers may be unwilling or unable to pay for in the form of higher prices. Wheat cleaning provides a classic example: To impose regulations across all participants in a marketing system such as that in the United States would violate the important principle that market participants can specify the cleanliness they want. Regulations therefore control the process and limit the range of qualities available, in contrast to a market where "anything goes" if buyer and seller agree.

Although all buyers may prefer a particular characteristic, all may not value it sufficiently to absorb the higher cost. Consider wheat dockage, for example. On the supply side, cleaner wheat can be produced and exported, as in other countries, by imposing regulations. End-users all prefer cleaner wheat but their reservation values—or willingness to pay—differ. Wheat millers in the United Kingdom, for instance, may have a high reservation value for clean wheat because they have to pay a Variable Import Levy on dockage equal to that of wheat. Or buyers with high per-ton transport costs or the need for extended storage (the costs of which increase with dockage levels) would have high reservation values for clean wheat. On the other hand, wheat importers with low transport costs and/or high resale prices for internal feed grains (an alternative use for wheat cleanings) would have low reservation values for clean wheat. In a competitive market, the distribution and allocation of the measured characteristic can easily be illustrated. Each buyer would have alternative contract specifications reflecting individual marginal reservation values. Buyers would specify contract limits by appropriately evaluating their values with the price differentials in the market.

Imposing a regulation on a quality level for all shipments has two general implications. First, the limit would have to be imposed on all shipments to preclude buyers with low reservation values from downgrading their specifications. Second, the result would be a higher overall price level, unless the cost were absorbed by lower producer prices, and some buyers with low reservation values would be excluded from the market.

One of the overall purposes of quality certification is to facilitate trade and to assure buyers of quality. Indeed, U.S. grain standards provide measures of physical quality and to some extent information to facilitate trade on those dimensions of quality. But, as noted, the quality of some grains regarding some intrinsic and sanitary characteristics is not necessarily resolved in the grain standards. Buyers' true preferences are for intrinsic characteristics such as loaf volume (bake test), farinograph measures in wheat, and oil and meal content in soybeans. None of these is measured in the marketing system for technical and institutional reasons. True performance cannot be assessed until after the purchase, and in many cases until use. As a result, buyers make purchases based on expectations of intrinsic quality that reflect reputation. Thus, it would be desirable to have a low variance with respect to these immeasurable intrinsic characteristics—resulting in more reliable expectations.

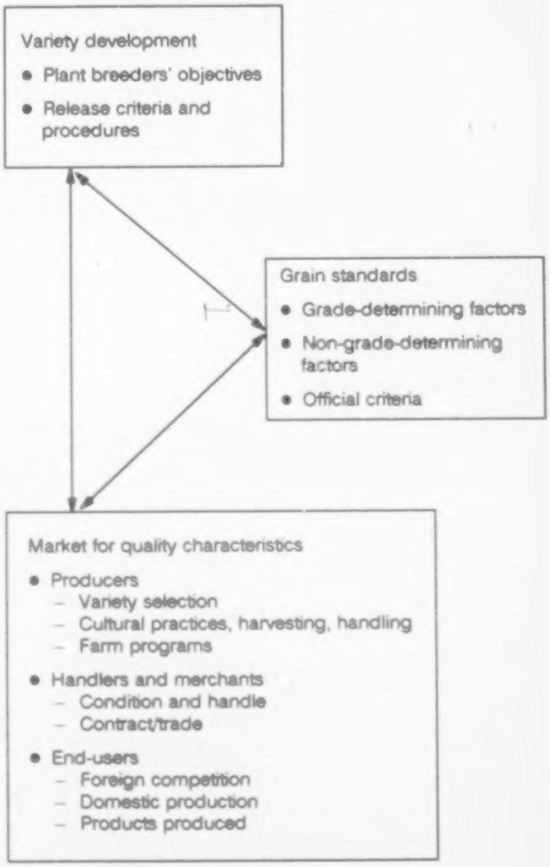
Information with respect to these quality characteristics is one-sided: Typically the seller has more information about quality than the buyer does at the point of negotiation. As an example, producers know the variety at the time of sale, but it is not revealed. Handlers know the extent or components of the blend, or the extent of conditioning, and this information is not revealed either.

This level of informational uncertainty provides an economic justification in general for sellers to provide certificates of quality. The role of certification is to reduce uncertainty for buyers, and therefore to facilitate trade. Traditionally certification via the grain standards is largely on physical, and somewhat on sanitary, characteristics. However, this is not the case with respect to important intrinsic characteristics. Thus one of the purposes of certification is elimination of uncertainty about quality, not only physical, but also sanitary and intrinsic. Accurate and relevant information therefore allows buyers to make purchases without conducting extensive testing, which would reduce liquidity of the market. As a result trade is facilitated, and transaction costs are reduced. One of the mechanisms to reduce this informational uncertainty is the grain standards. Others include controls earlier in the grain production system, such as variety release criteria. The impetus of these controls in a number of other countries is to reduce quality uncertainty in dimensions not easily measured by standards.

Interdependence of the Grain System

The interdependence in the production and marketing system with respect to quality is illustrated in figure 11-1. This triad could be viewed as a three-legged stool, with each leg having an impact on quality as well as on the overall system. Producers make varietal and agronomic decisions in response to incentives. These, as noted, are also influenced by farm

Figure 11-1.—Components of the Interdependent Grain System


Variety development
• Plant breeders' objectives
• Release criteria and procedures
Grain standards
• Grade-determining factors
• Non-grade-determining factors
• Official criteria
Market for quality characteristics
• Producers
– Variety selection
– Cultural practices, harvesting, handling
– Farm programs
• Handlers and merchants
– Condition and handle
– Contract/trade
• End-users
– Foreign competition
– Domestic production
– Products produced

SOURCE: Office of Technology Assessment, 1989

programs. The demand for characteristics is influenced by end-use needs and foreign competition. Merchants and handlers procure, handle, condition, and blend to meet contract specifications. In addition, they make offers on what they can sell, and at what price differentials, based on the availability of quality characteristics and their conditioning capabilities. Each of these activities are influenced by the incentives established in the market, by trading rules, and by grain standards. Blending to the factor limits specified in the standards is one example of this interaction.

Fundamental Policy Alternatives

The interdependence of variety development, the market for quality characteristics, and grain standards must be recognized in the evaluation of policy alternatives with the objective of a more integrated relationship between policies. A number of other exporting countries have more integrated and better coordinated policies than those of the United States. In fact, the United States has made no effort to coordinate and/or integrate policies affecting these activities. Policy interventions could be focused on any of the components of the system, but assessment of their effectiveness must include impacts elsewhere in the system. Any policy on grain standards, for example, will affect variety development and the efficiency of the market for quality characteristics. Similarly, any policy affecting the market (e.g., incentives) will have an impact on variety development and grain standards. The inability to measure intrinsic characteristics in grain standards has implications for policies affecting the market and variety development.

Policy cannot affect numerous phenomena that influence quality, such as weather, and a number of policies are short-run and only treat symptoms of the problem. The policies developed here aim to affect underlying causes of the problem, which over the long term will result in improved quality. They are limited to the three general categories of variety controls, market intervention, and grain standards (see table 11-1). The policy alternatives have been narrowed to these three to focus on those that appear to be most logical and likely to be effective in the long run. Only selected alternatives are presented in each category; in reality, a continuum of alternatives is likely, rather than having discrete choices as shown in the table.

Just as there is an interdependence in the system, the policy alternatives must interact. Controls over variety identification and release improve the efficiency of the market, and have the potential to act as a surrogate for intrinsic measures in grain standards. If variety release were controlled, there would be less of a need to measure intrinsic performance in the grain standards. Instituting incentives can also act as a surrogate for control of both intrinsic and/or physical and sanitary quality characteristics. In addition, depending on application, instituting incentives can indirectly spur variety development. By the same token, policies applied to grain standards affect both the market and variety development. Should intrinsic quality characteristics be measured in the grain standards, the market would establish incentives, which would be transmitted to producers and to variety development. If such characteristics are not measured, alternative mechanisms should be used. As mentioned, in

Table 11-1.—Fundamental Policy Alternatives

Variety controls	Market intervention	Grain standards
No change	Marketing board	Mandatory USGSA inspection
Variety identification/ categorization	Export bonus	Single agency to approve testing
Variety licensing	No change in loan policy	Mandatory USGSA inspection in conjunction with NIST equipment approval
	Increased differentials in government policies	
	Minimum quality specifications for farmer loans	

SOURCE: Office of Technology Assessment, 1989

most other exporting countries, the policies across these three sectors are coordinated and viewed systematically.

Variety Controls

Three important considerations lead to the policy alternatives listed under variety controls. First, with few exceptions grain standards do not measure important intrinsic characteristics. Second, intrinsic quality differs significantly across some varieties. Third, varieties are not visually distinguishable, thus segregation in the market system is precluded, resulting in increased uncertainty about quality. These three points apply to some extent to each of the grains, though their relevance—and thus the attractiveness of each alternative—varies. The classic case is that of wheat, in which performance varies across varieties and increasingly it is becoming difficult to differentiate wheats in the marketing system. In some of these cases it may be easier to identify variety, or groups of varieties, than intrinsic characteristics. Further, identity of a variety provides more comprehensive quality information than any subset of measured quality characteristics. To some extent, domestic processors attempt to resolve problems of varietal differences by purchasing by location or region. But foreign buyers, or any buyers using purely grade specifications, are precluded from this option.

No Change.—Five main effects of leaving the variety control system unchanged can be identified:

- *Continued lack of uniformity in intrinsic quality characteristics among States/regions/shipments.* In the current system with only informal, uncoordinated variety release criteria, many basic characteristics vary among varieties. These characteristics lose their identity in a market incapable of measuring end-use characteristics. As a result there are important intrinsic quality differences across regions of the country that are not detected in the marketing system.
- *Problems elsewhere in the system due to the inability to measure intrinsic quality.* In particular, greater pressure would be placed on grain standards to measure intrinsic quality within the marketing system.
- *Continued lack of information on intrinsic quality in some grains, and thus of current inefficiencies in the market.*
- *Productivity growth facilitated to a greater extent by having complete freedom on variety release and selection.*
- *Buyers seeking consistent intrinsic properties purchasing from exporters with less diversity.*

With no change from the current system of administering variety release, the pressure on grain standards to introduce measures of intrinsic quality would increase. Other countries use variety identification and release procedures in part to reduce pressure on the grain standards to measure intrinsic quality. Alternatively, by incorporating intrinsic quality into farm program policies (discussed later in this chapter), at least some incentive to improve intrinsic quality could be built into the sytem.

Variety Identification and Categorization.—Any sort of variety identification or control scheme would pose administrative challenges. One alternative would be to provide a mechanism (which does not currently exist) in which varieties can be identified in the market system, as done in other exporting countries. These consist of affidavit systems, random testing using electrophoresis, and categorization. Producers would declare the variety at the point of first sale or loan application. This would provide information to handlers on segregation based on categories of the grain, or groups of varieties. Categories would be developed according to end-use similarity, and could become part of the grain standards.

Alternatively, variety or groups of varieties could become part of the contract governing the transaction, as in France. The number of categories established would vary by grain, depending on the three considerations discussed earlier, and the end-use specificity. Thus, for example, if there were only one end use and the varieties did not vary sufficiently with respect to intrinsic quality, only one category would be necessary. On the other hand, for wheat with intrinsic differences across varieties and a multitude of end uses, there would be a larger number of categories. The intent here would be to formalize a mechanism not dissimilar from the current system of classification for wheat. The difference, however, is that the current system relies on visual distinguishability, and categorization is based on fairly imprecise criteria.

The implications of such a categorization system include:

- *An increase in information (by category of varieties), thus increasing the efficiency of the market in its allocative role.* For most grains, variety is a better indicator of quality than are selected tests for quality. Thus buyers' information regarding quality would be improved.
- *Improved signals transmitted to producers, breeders, and end-users through a more efficient market.*
- *A complex administrative program, especially given the large number of varieties currently grown in the United States.* Administration would be further complicated by the fact that intrinsic quality depends not only on variety, but also on location and climatic factors.
- *More complex contract specifications.* The informational requirements, particularly of foreign buyers, for contract specification would increase. Depending on the extent of categorization, however, this complexity could be reduced.

Introduction of a variety identification scheme would result in incentives and disincentives being readily associated with varieties having desired/undesired intrinsic characteristics. In addition, it would reduce pressure on the grain standards to measure intrinsic performance in the marketing system, as categorization of varieties would serve that function.

Variety Licensing.—A more restrictive approach would be to institute a variety licensing scheme. Varieties would be subjected to criteria administered at a national level for release into the market system. Licensing takes various forms in different exporting countries, from quite restrictive, as in Canada and Australia, to fairly neutral, such as the system in France. The intent of each though is to provide some mechanism that assures certain intrinsic characteristics (given that they cannot be easily detected in the market system) and to apply uniform criteria throughout the country, i.e., to reduce uncertainty of intrinsic characteristics through uniform application of release criteria. The program would require procedures similar to those of the variety identification system just described above. In addition, some criteria would have to be established for categorization (i.e., to license varieties by end use), and for administration.

Five effects of such a system can be identified:

1. increased uniformity, and an increase in the ability to control intrinsic quality;
2. a formal mechanism for categorization relative to a simple variety identification scheme;
3. depending on administration, a feeling of restrictions on productivity growth, although this is not necessarily the case, e.g., in France;
4. difficulty in administration, with complex enforcement, bureaucracy, and cumbersome implementation; and
5. licenses by location, due to differences in quality, and by end use.

A stricter variety licensing system would have similar impacts on interdependence discussed under the preceding alternative policy. In particular, licenses could act as surrogate grain standards for intrinsic characteristics.

Market Intervention

Marketing Board.—Central to the U.S. system is the market in which prices are established. Embedded in this market, and all prices, are premiums and discounts for measurable characteristics that serve to allocate grain across different users. In addition, these quality characteristics provide the incentives and disincentives for participants throughout the marketing system. Several other countries accomplish this by some form of board control.

Thus, one alternative in the United States would be to establish a marketing board system to resolve quality problems. The emphasis of the discussion here is on the implications of such a system for quality and the coordination of policies on quality. Other effects of a marketing board are more far-reaching (e.g., bargaining power, resource allocation, impacts on nonboard grains, and impacts on physical coordination) and are not discussed. The major implications of a board with respect to quality are:

- *Coordination of the many aspects of the production and marketing system that have an impact on quality.*
- *Improved quality to the extent that only two transactions—one between producer and board, and another between board and buyer—would take place in the marketing system.* This is in contrast to the multitude of current transactions, all requiring measurement of quality.
- *More subjective and judgmental administration of price differentials, since transactions would take place without an active market.* Market determination of price differentials is an important advantage of the current U.S. system.
- *High cost, given the complexity and breadth of the U.S. marketing system.* Countries that already have boards operate in relatively simple logistical systems, and cover few grains. As either of these increase, as they do in the United States, the problems associated with bureaucratic allocation of decisions intensifies.
- *Loss of the highly efficient U.S. grain handling and distribution system that stems, in part, from the competitive environment.*

A board system could reduce the emphasis on grain standards at the point of export, and for that matter throughout the system, if sufficient controls were imposed early in the system to resolve grain quality problems, thereby reducing the importance of quality measurement at the point of export. In addition, variety release procedures could be easily administered in a board system. Incentives could be administered rather than relying on market determination.

Overall, however, the costs of introducing a board system in the United States would likely outweigh the benefits of quality improvements.

Export Bonus.—An alternative policy would be to establish a bonus payable to exporters who deliver quality superior to contract specifications. This policy is discussed as being applied at the point of export, but it could be applied elsewhere in the marketing system. The major implications of this approach are:

- *Immediate results, especially if the program were tied to a physical or sanitary quality characteristic.* However, longevity should be a concern, in that if terminated, the effects would not likely last.
- *Administrative questions.* First, which quality characteristic(s) should be tied to the bonus—physical, sanitary, or intrinsic? Quality would improve on whatever characteristic the bonus were applied to. Depending on the length of the program, however, the bonus would likely not influence intrinsic quality. Second, should the bonus be applied at the point of export, or the point of origin?
- *The cost of administration, and/or a direct outlay, to finance the program.*
- *A risk that importers may manipulate the system by specifying a lower grade, in order to receive the same grade they traditionally purchase, but at a lower price.*
- *An increase in perception of quality, or of attention to the issue.*

An export bonus program, by definition, would be oriented to the merchants and handlers in the system. It would provide incentives for them to improve the quality of particular attributes or particular shipments to which the bonus were applied. Due to competition within the industry, any benefits would be distributed to appropriate decisionmakers so as to provide incentives. Given that more information would not be provided to the market, and that information uncertainty would not be reduced, the efficiency of the market would not be improved. Breeders' objectives and release criteria would be affected only to the extent that the bonuses were applied to intrinsic characteristics, and to the extent they were applied over very extended time periods.

No Change in Loan Policy.—The current administration of the policy on loan forfeitures and Commodity Credit Corporation (CCC) grain storage policies could remain the same (see ch. 9). The fundamental problem is that price differentials for loan forfeitures and transactions on CCC-owned grain are substantially less than those in the market. Implications of no change from the current status are:

- *A distorted market for quality characteristics.* The loan and CCC storage practices would continue to support the price of lower quality grains. In addition, the intrinsic, physical, and sanitary quality of U.S. grain would be unchanged.
- *Grain under extended storage, which would potentially deteriorate more than if grain of superior physical and sanitary quality were stored.*
- *Growers isolated from the market, which masks the incentives for improving quality.*

In general, the market today is distorted in the allocation between storage and commercial sales, with superior-quality grain going to the latter. Since the program does not effectively distinguish intrinsic quality, loan rate disincentives do not transmit signals to producers. Thus, a major impact of not changing the policy would be to increase the role and function of grain standards in measuring quality.

Increased Differentials in Government Policies.—In a number of other countries quality problems are addressed as a matter of agricultural policy. These take the form of incentives by using regulations and substantial premiums and discounts for quality deviations. Realigning the incentive system via farm policy addresses one component of the system, i.e., the market for quality characteristics. That market already exists and develops premiums and discounts. But it is distorted somewhat by administration of the farm program. Thus, this policy alternative could be seen as merely eliminating a distortion, which would allow the market to function more efficiently. Alternatively, farm policy could take the lead by providing price differentials at least equal to market differentials, to provide incentives throughout the system.

As discussed in chapter 9, CCC administers programs for handling and storing CCC-owned grain. Different rules are applied to country and terminal elevators. CCC requires that terminal elevators deliver the quality that is represented by the warehouse receipts, and it discounts individual railcars. CCC does not pay terminal elevators for overdeliveries in quality. This is not the case for country elevators, which are not subject to the same rejection rules if the quality delivered is inferior to the warehouse receipts and which receive payment for overdeliveries.

One of the few ways to legislate incentives into the system, particularly for intrinsic quality, is via the price differentials for loan forfeitures and transactions involving CCC-owned grain. This alternative consists of loan-associated price differentials greater than or, alternatively, equal to the market. They could be applied as currently done, on grades, or could use specific physical and sanitary quality criteria. A simple example would be a 4 cents/bushel price differential for clean wheat (i.e., less than 0.5 percent dockage). In addition, measures of intrinsic quality (e.g., falling number in wheat, oil content in soybeans, protein content in corn) could be incorporated, as they are in other countries.

The implications would be as follows:

- *A greater impact on wheat than other grains, because the relationship between market prices and loan values varies across grains and because participation rates vary.* In addition, the impact itself would vary, due to the loan being effective only periodically.
- *Grain of lower value being forced onto the market, as opposed to going into the loan program, as it currently does.* This implies also that the loan program would support prices of higher quality grains.
- *An increase in the amount of grain going*

into alternative uses, with lower end value. The most vivid example is wheat feeding.

- *Incentives for intrinsic quality relatively easily incorporated into the loan program (more easily, that is, than measuring them in the marketing system).*
- *The development of a mechanism for measuring quality of grain going under loan, perhaps through samples submitted by farmers.*
- *Difficult administration of optimum price differentials.* This is especially true given the large number of markets in the United States, and given that—at least in the past—loans have to be announced long before crop quality is realized.
- *Country elevators forced to become more concerned with maintaining quality.* Also, CCC would be guaranteed that the quality of grain received into the country elevator would be delivered out of the elevator. This change in policy would relieve the pressure of maintaining discount schedules that reflect the market in that CCC would not accept quality below that called for by warehouse receipts.

This particular alternative addresses the market for quality characteristics and provides incentives in an important market for some grains. Such a change could have a number of systemwide benefits. First, to the extent that intrinsic characteristics are used, variety development would be favorably affected. Signals from this important market would be directly transmitted to breeders and would affect their objectives and release criteria. Thus it would provide somewhat of a surrogate for variety control. Second, there would be somewhat reduced pressure to measure intrinsic quality in grain standards. In the extreme of a proactive farm policy, together with variety identification/licensing, the role and function of grain standards could to some extent become one of measuring only physical and sanitary quality characteristics.

Minimum Quality Specifications for Loans. — Many countries have minimal receival standards on grain entering the marketing system. Normally grain marketing is integrally related to prices and policies (e.g., initial payments) and therefore it is difficult to isolate physical marketing from pricing. As developed here, minimum quality specifications would be applied to grain entering the loan program as opposed to when it entered the marketing system. The global application of minimum quality specifications to the U.S. marketing system would be next to impossible to implement since a majority of grain under loan is stored on farms.

The concept of setting minimum quality specifications for loans is similar to the option just discussed except that a constraint, rather than a price incentive, is being used for entry into the loan program. Minimum quality specifications could be applied to physical characteristics (e.g., minimal dockage) or intrinsic characteristics (e.g., variety, protein, falling number, oil, or meal protein).

Under this policy alternative, the potential exists that grain not meeting specifications would be diverted to the export market or a lower valued market. One way to help minimize diversion to the export market would be to use whatever quality specification has been established for government programs as a basis for rejecting grain going into an export elevator. This would have the added benefit of reducing the spread of qualities available for blending within the export elevator; however, blending of wide ranges in quality would still occur in country/terminal facilities. As discussed in the next section of this chapter, mandatory inbound inspection into export elevators could serve as the basis for rejecting or accepting grain.

The first five implications of increased differentials in government policies would also apply to this alternative. Other implications are:

- *Minimum quality specifications, which would be difficult to establish and maintain in the current political environment.*
- *Desirable quality characteristics incorporated in the loan program.* These could also be characteristics not easily measured in the marketing system.

- *Depending on the minimum quality specifications (physical, sanitary, intrinsic, or variety), a requirement for farmers to certify the variety planted or take samples of stored grain for testing as directed by the U.S. Department of Agriculture (USDA).*

Use of minimum quality specifications could also solve or contribute to the resolution of problems elsewhere in the system. Desirable varieties or intrinsic characteristics, if used, would transmit signals to breeders, influencing their objectives and release criteria. In addition, to some extent, the role and function of grain standards in measuring intrinsic quality in the marketing system could be reduced.

Grain Standards

The United States Grain Standards Act (USGSA), states that it is Congress' intent to promote the marketing of high-quality grain to both domestic and foreign buyers and that the primary objective for grain standards is to certify grain quality as accurately as practicable. Embedded in this policy are four basic objectives for grain standards:

1. to define uniform and accepted descriptive terms to facilitate trade,
2. to provide information to aid in determining grain storability,
3. to offer users of such standards the best possible information from which to determine end-product yield and quality, and
4. to provide the framework necessary for markets to establish grain quality improvement incentives.

Chapter 8 assessed the ability of the grain standards to meet these objectives. In several areas the current standards fall short. However, an ideal grain standard that encompasses all four objectives may be difficult to achieve, and trade-offs between objectives may be necessary. The criteria for standards laid out in chapter 8 in terms of the number of grades and what should constitute grade-determining, nongrade-determining, and official criteria provide a framework for incorporating the four objectives into grain standards.

The grain standards, if modified along these lines, would facilitate trade by providing a limited number of grades and grade-determining factors. Incorporating some factors as nongrade-determining or even official criteria allows the market to set values for these factors that will send signals throughout the system for quality improvement, if warranted. To a limited degree, this structure will provide information important to end-users, who will establish the limits that best suit their needs. Until new technology is developed for measuring intrinsic quality and several sanitary quality attributes, however, the standards cannot begin to reflect many of the objectives.

To comply with the objective of certifying grain quality as accurately as practicable, the USGSA provided several legislated mandates. First, it authorizes the Federal Grain Inspection Service (FGIS) Administrator to establish, amend, or revoke standards whenever their usage by the trade may warrant or permit. Second, whenever standards are in effect, the standard must be used to describe the grain being sold in interstate or foreign commerce. Third, the FGIS Administrator is authorized to provide for a national inspection system. Finally, whenever standards are in effect, the grain must be inspected by FGIS as it is being exported from the United States. As pointed out in chapter 8, even though the standards must be used to describe grain being sold overseas, no requirement exists for inspecting grain moving in domestic markets. Therefore grain can move domestically without inspection and, when inspected, can be checked by FGIS or a FGIS-licensed inspector, private inspection companies, individuals employed by a grain-handling facility, or individuals licensed by the Warehouse Division of USDA's Agricultural Stabilization and Conservation Service.

Several important ramifications for grain quality result from this policy. Since no single agency is responsible for testing grain according to the standards or any other set of specifications, no agency is responsible for developing the equipment and procedures used to sample and measure these factors or for overseeing the equipment, methods, and accuracy of results. For the market to properly assess premiums and discounts for quality characteristics, testing results for these attributes must be measured as accurately and consistently as measurement technology will allow. End-users rely on accurate measurement of important quality characteristics in purchasing and production decisions, and inaccurate results can lead to quality complaints and product yield and quality below expectations. (Ch. 8 describes the integral components for developing, maintaining, and standardizing testing procedures, and discusses testing accuracy and sources for testing errors.)

Since the grain standards serve as the basis for marketing grain and providing information on important quality characteristics to all users, the factors selected for measurement by the standards are important. Even more important is the way they are measured and the consistency of measurement. As new tests are added to the standards, there is no requirement that the testing technology developed and approved by FGIS as the basis for the standard must be used to measure the attribute.

In other instances, no requirement exists for how samples will be obtained, who will perform the tests, or even whether any test contained in the standard will be performed. Chapter 8 identifies problems associated with obtaining samples and the impact on accuracy of the type of equipment and amounts obtained. With regard to obtaining inspection, the recent inclusion in the wheat standard of the Food and Drug Administration (FDA) defect action limit of 32 insect-damaged kernels per 100 grams of wheat restricts the amount of insect-damaged kernels in the various grades to a level that coincides with the FDA limits. This change has caused a decrease in the number of requests for inspection under the USGSA because many shipments exceed the FDA defect action limit and FGIS must report any such cases to FDA. Therefore, the change has not provided FDA with the information it requires to act on such shipments, and wheat that exceeds the limits is still handled to some degree as it was before the change.

In addition, the USGSA allows FGIS to use delegated and designated agencies to perform inspections on its behalf. Designated agencies are independent businesses that rely on fees generated by performing inspections. Since designated agencies perform inspection services on request, the potential exists for these agencies to perform less than accurate inspections because of the need to keep their customers satisfied. This places USDA-approved agencies in the same position as independent, nongovernment businesses whose sole aim is to satisfy the paying customer.

Other potential conflicts arise from not specifying how the standards will be implemented. Since inspections on domestic grain shipments are performed on request, they can also be dismissed. The potential impact on grain quality is that a request can be dismissed and the grain shipped if it is discovered during the course of the inspection that the quality is not up to specification. For example, if sour grain is found and reported to the elevator manager during the sampling of a barge being loaded, the elevator manager can dismiss the inspection request. If the sales contract calls for an "official grade," the manager can call for the barge to be sampled at rest. In this instance, the portion of sour grain that was previously discovered during loading will be commingled in the barge and probably not found during sampling.

Several policy alternatives exist for developing a program to reduce the potential for testing inaccuracies and provide consistently accurate results—mandatory USGSA inspection on domestic grain moving in interstate commerce, the creation of a single agency to approve and oversee testing equipment and procedures, or a combination of these two approaches.

Mandatory USGSA Inspection.—As noted, FGIS establishes standards, which includes developing technology to measure the factors contained in the standard. The agency also develops and publishes sampling and inspection procedures, evaluates and approves equipment for use during inspection, monitors inspection accuracy of its employees and licensed inspectors, and periodically tests sampling and inspection equipment for accuracy. Therefore, a basic structure is in place for approving and overseeing all equipment and procedures used for measuring grain quality characteristics.

At one time mandatory inspection was required on all grain moving in interstate commerce. This provision was deleted from the USGSA by Congress in the late 1960s because of the difficulties in enforcing it on truck shipments. It was at that time that the provision requiring the use of the standards for merchandising grain was included in the USGSA.

The implications of requiring mandatory inspection on interstate grain shipments, including adoption of the best possible sampling technology, are as follows:

- a reinforcement of the policy that standards must be used to describe grain being bought and sold and that the factors covered by standards are tested using approved equipment and procedures as the basis for the test;
- consistency in test results in that identical procedures are used for each inspection in the marketplace and are performed by independent government-sponsored agencies;
- primary responsibility for grain quality measurement focused on one government agency;
- use of the existing basic framework through the delegated and designated agencies who already own approved equipment and have trained employees that use FGIS-published procedures;
- applicability to railcar and barge shipments only, as the ability of delegated and designated agencies to cover the wide areas required to meet the needs of country elevators receiving trucks is severely limited; and
- increased costs associated with obtaining inspection on grain that would otherwise not need to be inspected (i.e., grain moving from one facility to another owned by the same company).

Single Agency to Approve Testing.—As discussed in chapter 8, the National Bureau of Standards (renamed the National Institute of Standards and Technology* (NIST)), through the National Conference of Weights and Measures, standardizes weights and measures by developing specifications for instrument precision and accuracy along with scale tolerances, and maintains national standards. Currently, NIST addresses neither grain measures other than weights nor sampling equipment. In some instances, individual States have taken it upon themselves to develop criteria for approving inspection equipment and monitor the equipment accuracy. (Moisture meters and mechanical truck probes are prime examples.) In addition, the grain-industry-sponsored Grain Quality Workshops recommended that NIST take the lead in developing and overseeing moisture meter calibrations.

NIST, in consultation with FGIS, could take the lead in developing and maintaining equipment specifications and maintenance tolerances. These actions could be in conjunction with FGIS developing new tests to be included in the standards. NIST approval could be the basis for approving equipment (including sampling equipment) for use by FGIS when performing inspections and could be administered by the individual States for testing not performed under the USGSA. Many States currently have agencies responsible for grain-handling facilities (country as well as terminal elevators) within their jurisdiction. And several States have already established procedures for approving and testing moisture meters and sampling devices. The basic framework is in place for establishing a central body to approve and oversee the equipment used in conjunction with grain quality testing.

The need for standardized testing procedures for sampling devices, moisture meters, and near infrared reflectance (NIR) equipment is apparent. As more uses for NIR and other sophisticated tests are found to provide important quality information to buyers and sellers, the need for standardized testing will become more critical, especially on farmer-owned grain at the country elevator level.

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*The National Bureau of Standards was recently renamed the National Institute of Standards and Technology (NIST) with the passage of the Omnibus Trade and Competitiveness Act of 1988 (Public Law 100-418) as of August 1988.

The implications of giving NIST responsibility for approving and overseeing inspection equipment are:

- *Standardized equipment to measure grain quality attributes that could be traced back to national standards.* Variations in testing results introduced by a wide range of equipment accuracies is reduced.
- *Use of only approved equipment to provide testing results, with NIST oversight to ensure accurate testing.*
- *Use of the existing basic framework.* NIST already has established approval procedures, publishes user requirements, and enforces its provisions through State organizations.
- *Placing responsibility for approving grain testing equipment in an agency that does not have a vested interest in the equipment's use.*
- *An inability to cover tests that are subjective in nature, such as odor, wheat classing, and determination of damaged kernels.*
- *A lack of experience in basing a national standardization program on reference methods that are defined rather than proven.*
- *Increased costs for those that have to dispose of unapproved testing equipment and purchase approved equipment.*
- *Avoidance of the issues of who will use the equipment and when it will be used.*

Mandatory USGSA Inspection in Conjunction With NIST Equipment Approval.—A policy that requires mandatory USGSA inspection on grain moving in interstate commerce and a broadening of NIST involvement into grain sampling and testing equipment captures the advantages of the last two options while minimizing many of the disadvantages.

The advantages of mandatory inspection on railcars and barges moving in interstate commerce ensures that consistent sampling and testing is performed on both subjective as well as objective factors and that one agency is responsible for grain testing as well as standards development. The inability to perform USGSA testing on trucks and at country elevators can be compensated for to some extent by involving NIST and its related support systems in the grain-testing area. Even though USGSA inspection would not be performed, those groups that do perform testing would be required to use approved equipment and to follow the user requirements spelled out in the NIST approval. This would be the same requirements that USGSA inspectors follow, since FGIS would also be using NIST-approved equipment and user guidelines.

This policy alternative allows country elevators to continue to perform their own tests on grain received from the farmer, thus reducing the potential increase in costs associated with mandatory USGSA inspection. But it would create more uniform testing since anyone performing grain quality testing will be required to use NIST-approved equipment and follow published user requirements. Coupled with the NIST State support systems already in place to oversee equipment accuracy and ensure that user requirements are followed, NIST involvement would provide oversight in areas not previously subjected to it.

Interactions Between Standards, Variety Control, and Market Intervention

The policy alternatives outlined in the variety control section address intrinsic quality characteristics, since physical and sanitary quality cannot be addressed through such programs. The policy choices discussed in the market intervention section can address the easily measurable factors for physical and sanitary quality, and can be expanded to deal with intrinsic quality attributes once technology is developed to measure them in the marketplace. Each section cited examples of the expected impacts on grain quality and standards.

In both the variety control and market intervention sections, an option for no change in present policies has been provided. Such an approach places the responsibility for physical, sanitary, and intrinsic quality solely on grain standards. For the physical and many of the sanitary quality concerns, relying on the grain standards is a relatively simple matter that does not involve the adoption of new technology. It involves taking existing factors and applying the criteria developed in chapter 8. Several factors could be combined (as is the case of foreign material and dockage in wheat, as many have suggested, as either grade-determining or non-grade-determining) or factors could be separated (as is the case with broken kernels and foreign material in corn) to describe quality more accurately. In addition to rearranging existing factors into grade-determining, non-grade-determining, or official criteria, fixed percentages could be established for certain factors that transcend all grades (e.g., maximum level of dockage in wheat or maximum moisture levels in corn and soybeans). Limits for current factors (e.g., live insects or stones) could also be tightened.

Making no change to variety control systems or market intervention has a dramatic impact on the grain standards, however, in that they must be able to address the buyer's desire for information on important intrinsic characteristics and take the lead in establishing the signals regarding quality for the entire system. Presently, technology to easily measure intrinsic attributes in the marketplace is not available. If the standards are to be the vehicle for providing information on intrinsic and many new sanitary quality characteristics (e.g., pesticide residue), resources must be provided to develop the technologies needed to accurately and easily measure them before the market can respond. It will take years to research and develop new tests that could be put on-line before signals begin to be transmitted back through the system.

In addition to identifying what factors the standards should measure and whether factors are grade-determining, non-grade-determining, or official criteria, the way the standards are implemented can also have a dramatic impact on grain quality. One of the major problems facing the United States in terms of grain quality—whether physical, sanitary, or intrinsic—is that all grain, no matter the quality, is accepted into the system and marketed. This places enormous strain on the system's handling and inspection capabilities and is the cause for most of the blending controversies. Adding new tests to the standards or applying the criteria developed in chapter 8, including limiting the number of grades, will not resolve the problems associated with blending extremely high-quality with extremely low-quality grain.

As discussed in chapter 8, limiting the spread between grades will reduce the opportunity for blending. On the surface this appears to be a viable option. But the expected impacts from such a change assume that the grades being traded will remain the same. If the spread between grades is reduced and the trading grades are lowered, the opportunity for blending will remain the same. Even removing factors from being considered grade-determining does not in and of itself remove the incentive for blending. An example of this is provided by the recent change whereby moisture was removed as a grade-determining factor, forcing limits to be established in contracts. The change has not removed the incentive for blending wet and dry grain in order to meet contract specifications.

SUMMARY AND CONCLUSIONS

The U.S. production and marketing system is a highly interdependent system of activities. Any policy designed to enhance grain quality (physical, sanitary, or intrinsic) must address this interdependence. Traditional policy discussions, however, have focused on only one component—grain standards. But a properly functioning market can solve many of the grain quality problems. Therefore, a fundamental policy alternative would be one that creates an environment that would improve market efficiency. In addition, appropriate quality information must be provided so that relevant incentives and disincentives can be established to improve market efficiency.

Just as there is system interdependence, there is interdependence of policy alternatives. Controlling variety release, for example, could improve market efficiency and act as a surrogate for intrinsic quality measurement. This reduces the impact of forcing grain standards to measure intrinsic quality characteristics in order to provide incentives. Market incentives can regulate physical, sanitary, and easily measurable intrinsic quality characteristics. The market can provide incentives in variety development while policies applied to grain standards affect both the market and variety development.

Given the interdependence of the system, policy could be focused on any one component. However, if grain quality is truly a result of the total system, then the success of policy changes to any one component must be assessed in terms of this interdependence. If existing policies for variety control and/or market intervention remain unchanged, the entire responsibility for improving quality will be placed on grain standards. For contrast, policy changes to variety control will improve the information for intrinsic quality characteristics needed by the market and reduce the need for grain standards to shoulder the entire burden.

Policy alternatives for enhancing grain quality have been divided into three general categories for the purpose of this assessment—variety controls, market intervention, and grain standards. One possible policy path that maximizes the strengths of the various options as well as minimizes their weaknesses is to adopt variety identification/categorization, increase the differentials in loan policy and specify minimum quality for farm loans, and introduce mandatory USGSA inspection in conjunction with NIST equipment approval.

Introducing a variety identification scheme would improve information on intrinsic quality characteristics, thus reducing the pressure on grain standards to measure intrinsic performance in the market. For most grains, variety is a better indicator of quality than are selected tests. The increased information resulting from variety identification would raise the efficiency of the market, resulting in incentives/disincentives being transmitted to producers, breeders, handlers, and end-users. Variety identification alone, however, does not address physical or sanitary quality concerns, so these concerns must be addressed by other areas.

Removing the distortion created by the current administration of premiums and discounts for loan forfeitures and applying the same rules to country and terminal elevators storing government grain would allow the market—which has already established premiums and discounts—to function properly. Grain of lower value would be forced onto the market as opposed to entering government programs. To the extent that intrinsic quality characteristics are included, variety development would be affected. Signals from government programs, directly transmitted to farmers, would affect their decisions on varieties planted, thus influencing breeders' objectives and release criteria.

Setting minimum quality specifications for loans places an additional constraint on entry into the loan program. These could easily be applied to physical and sanitary quality characteristics as well as measurable intrinsic characteristics and, along with the variety identification scheme, would reinforce signals being transmitted throughout the system. Farmers would be required to obtain testing of grain that was in the loan program and being stored on farm, rather than self-certifying quality as is presently the case.

Implementing such policies on government programs and minimum quality specifications will force lower quality grain into the export market. Therefore, minimum quality specifications established for entry into government programs could be applied to grain entering export elevators. This would transmit signals for improved quality throughout the system and would reduce the spread of qualities available for blending at export locations.

The need for accurate measurement of important characteristics—whether physical, sanitary, or intrinsic—is crucial to providing information for the market to function properly. The vehicle by which quality information is transmitted throughout the system is grain standards. Incentives and disincentives cannot be established unless accurate, consistent, and timely information is provided in the market. This can be accomplished by continued efforts to incorporate the four objectives of grain standards, by implementing mandatory inspection, and by increasing NIST involvement in approving grain sampling and testing equipment.

Mandatory inspection of railcars and barges would ensure that consistent sampling and testing is performed. Used in conjunction with minimum quality specifications on grain entering export elevators, this would ensure that one government agency is responsible for quality testing. The increased presence of NIST in approving grain sampling and testing equipment would ensure that all parties testing grain quality use approved equipment and follow basic user requirements.

As discussed throughout this chapter, the interdependence between variety control, market intervention, and grain standards is complex. Grain quality is a function of the variety planted, farmer practices, environment and geographic location, handling practices, end-user preferences, marketing, government policies, and the ability of grain standards to provide information on important quality characteristics. Policy changes, therefore, must create an integrated policy for enhancing grain quality. Potential conflicts, overlapping benefits, and limitations of certain policy options must be recognized and addressed.

Appendixes

Appendix A

Glossary of Acronyms

AMA	—Agricultural Marketing Act
ASCS	—Agricultural Stabilization and Conservation Service (USDA)
ASW	—Australian Standard White wheat
BCFM	—broken corn and foreign material
CCC	—Commodity Credit Corporation
CIF	—cost, insurance, and freight
CSRS	—Cooperative State Research Service
CWRS	—Canadian Western Red Spring wheat
cwt	—hundredweight
DNA	—deoxyribonucleic acid
D/T	—diverter-type
EC	—European Community
ELISA	—enzyme-linked immunosorbent assay
ESCOP	—Experiment Station Committee on Policy
FAQ	—fair average quality
FDA	—Food and Drug Administration (PHS, DHHS)
FDCA	—Food, Drug and Cosmetic Act
FGIS	—Federal Grain Inspection Service (USDA)
FOB	—free on board
GAFTA	—Grain and Feed Trade Association (UK)
HRS	—Hard Red Spring wheat
HRW	—Hard Red Winter wheat
NAEGA	—North American Export Grain Association Inc.
NIRS	—near-infrared reflectance spectroscopy
NIST	—National Institute of Standards and Technology (Department of Commerce)
OSHA	—Occupational Safety and Health Administration (Department of Labor)
OTA	—Office of Technology Assessment (U.S. Congress)
PVRC	—Plant Variety Review Committee (University of Illinois)
SAES	—State Agricultural Experiment Station
SMV	—soybean mosaic virus
SRW	—Soft Red Winter wheat
SWQAC	—Spring Wheat Quality Advisory Committee
UGSA	—Uniform Grain Storage Agreement
USDA	—U.S. Department of Agriculture
USGSA	—U.S. Grain Standards Act
U.S.S.R.	—Union of Soviet Socialist Republics
VRC	—Variety Release Committee

Appendix B
Glossary of Terms

Adulterated grain: According to the Food, Drug and Cosmetic Act, grain is deemed to be adulterated if it contains an added or naturally occurring poisonous or deleterious substance that may render it injurious to health (e.g., aflatoxin-contaminated corn).

Aeration: The passage of air over or through grain to control the adverse effects of excessive moisture, temperature, and humidity. This is usually done by moving air with fans or through ducts.

Aflatoxins: Any of several mycotoxins that are produced, especially in corn or oil seeds, by molds (e.g. aspergillus flavus).

Agronomy: A branch of agriculture dealing with field crop production and soil management.

Allele: One of several possible alternate forms of a given gene.

Amino acid: A group of 20 molecules that bind together to form proteins. Each type of protein is made up of a specific sequence of amino acids coded for in the DNA.

Amylase: Any of the enzymes that accelerate the hydrolysis of starch and glycogen.

Amylopectin: A component of starch characterized by its heavy molecular weight, its branched structure of glucose units, and its tendency not to gel in aqueous solutions. The starch of normal corn is made up of amylopectin and amylose.

Amylose: A component of starch characterized by its straight chains of glucose units and the tendency of its aqueous solutions to set to a stiff gel. The starch of normal corn is made up of amylopectin and amylose.

Backcross: The crossing of a first-generation hybrid with either parent.

Bin-dryers: On-farm dryers that are generally low-capacity, low-temperature systems, capable of producing excellent quality grain.

Biochemistry: A branch of chemistry that deals with the chemical compounds and processes occurring in living organisms.

Biotechnology: Techniques that use living organisms or substances to make or modify a product. *See* genetic engineering and recombinant DNA.

Blending: For purposes of this assessment, blending refers to the mixing of two or more grain lots to establish an overall quality that may or may not be different from any one individual lot. Blending is done for economic reasons, to achieve uniformity for improved handling, or to meet a particular quality specification.

Broken corn and foreign material (BCFM): Any material passing through a 12/64 inch sieve, plus non-corn material remaining on top.

Bromus Secalinus (cheat): Any of several grasses, especially the common chess. This weed is a major problem for winter wheat producers in the central Plains.

Callus: Unorganized tissue formed from organized plant tissue.

Carbohydrate: Any of various neutral compounds of carbon, hydrogen, and oxygen (such as sugars, starches, and cellulose) most of which are formed by green plants.

Chromosome: A thread-like structure contained in the nucleus of a cell that carries the genes that convey hereditary characteristics.

Cleaning: For purposes of this assessment, cleaning is the removal of dockage, insects, and to a degree shrunken and broken kernels from grain by means of mechanical screening and scalping devices. Cleaning practices vary from country to country. *See* precleaning.

Combination dryers: On-farm dryers, mainly used for corn, that combine the best characteristics of bin and non-bin systems (i.e., high quality and high capacity), but are more complicated and expensive.

Combine: A machine that harvests grain. The first combine was patented in 1836, since then self-propelled combines of either conventional or rotary design have evolved and come into use throughout the United States and in other countries.

Concurrent-flow dryers: Off-farm commercial dryers in which grain and air flow vertically. The gentle drying and cooling methods used in these dryers results in grain of superior quality. Their main disadvantage is their high initial cost.

Corn: The seed of a cereal grass and the only important cereal plant indigenous to America. Corn is used mainly for animal feed, but it is also used for oils, starches, and syrups for human consumption, and in some industrial products. It is grown extensively in the United States, the six Corn Belt States are Iowa, Illinois, Indiana, Nebraska, Minnesota, and Ohio.

Cotyledon: The seed leaf of an embryo plant that serves as nourishment for the elementary plant.

Crossflow dryers: The most prevalent type of off-farm commercial grain dryers in the United States, in which grain and air flow in a perpendicular direction. This type of dryer tends to dry the grain non-uniformly, causing stress-cracking of the kernels.

Cross-pollination: The transfer of pollen from one plant to another plant.

Cultivar: An international term denoting certain cultivated plants that are clearly distinguishable from others by one or more characteristics, and that when reproduced retain those distinguishing characteristics. In the United States "variety" is considered to be synonymous with cultivar (derived from cultivated variety). *See* variety.

Cytoplasm: The protoplasm of a cell outside the nucleus consisting of an aqueous solution, which is the site of most of the chemical activity of the cell.

Deficiency payments: Payments to farmers based on actual planted acres, which make up the difference between a politically acceptable target price, and the average market price or loan rate, whichever is higher.

Degermination: The process whereby the corn kernel is broken apart into endosperm, germ, and pericarp.

Deoxyribonucleic acid (DNA): The nucleic acid in chromosomes that codes for genetic information. The molecule is double stranded, with an external "backbone" formed by a chain of alternating phosphate and sugar (deoxyribose) units and an internal ladder-like structure formed by nucleotide base-pairs held together by hydrogen bonds.

Dockage: The foreign material in market grain (such as stems, weeds, and dirt), which is readily removable by ordinary cleaning devices.

Drying: For purposes of this assessment, drying is the removal of moisture from grain by various methods in both commercial and on-farm dryers. Air temperature, grain velocity, and airflow rate during the drying process have a greater influence on grain quality than all the other grain handling operations combined.

Dry milling: The basic process used to mill wheat and corn, involving the cleaning, conditioning, grinding, and sifting of the grain.

Electrophoresis: A technique used to separate molecules (such as DNA fragments or proteins) from a mixture of similar molecules. By passing an electric current through a medium containing the mixture each type of molecule travels through the medium at a rate corresponding to its electric charge and size. Separation is based on differences in net electrical charge and in size or arrangement of the molecule. This technique can be used to identify grain varieties.

Elevator leg: Part of the belt-bucket system used in commercial grain facilities. It consists of an endless vertical belt with buckets spaced evenly along it. The buckets scoop up the grain at the bottom (boot) of the leg and discharge it at the top.

Endosperm: A nutritive tissue in seed plants contained in the inner bulk of the kernel that consists primarily of complex carbohydrates. It also contains protein, riboflavin, and B vitamins. In corn, the quantity of vitreous or horny endosperm relative to floury endosperm in the kernel determines the hardness of the grain.

Environment: The complex of climatic, edaphic, and biotic factors that act upon an organism or an ecological community and determine its form and survival. The environment in which it grows greatly influences the productivity and quality of grain.

Enzyme: Any of a group of catalytic proteins that are produced by living cells and that mediate and provide the chemical processes of life without themselves being destroyed or altered.

Enzyme-linked immunosorbent assay (ELISA): A test that is used to identify proteins and plant pathogens by using antibodies to identify proteins rapidly. A protein-antibody complex is incubated with an enzyme-coupled antibody that recognizes and binds to the protein. The reaction is measured spectrophotometrically to identify the presence of the specific protein that is attached to the antibodies.

European Economic Community (EC): A group of twelve European nations, consisting of Belgium, the Federal Republic of Germany (West Germany), France, Italy, Luxembourg, the Netherlands, the United Kingdom (UK), Ireland, Denmark, Greece, Spain, and Portugal that have banded together for economic and political reasons.

Federal Grain Inspection Service (FGIS): A branch of the U.S. Department of Agriculture that establishes grain standards and develops the technology to measure the factors contained in such standards. This agency also develops and publishes sampling and inspection procedures, evaluates and approves equipment, monitors inspection accuracy, and oversees mandatory export inspection of grain by FGIS or FGIS-licensed inspectors.

Feed grains: Grains, especially corn, characterized as high-energy grains due to their relatively high levels of nitrogen-free extract and low levels of crude fiber.

Flaking grits: A product of dry-milled hard corn.

Low-fat, large flaking grits are used primarily in the manufacture of breakfast food, and coarse and regular grits are used in the brewing industry.

Flour: Finely-ground meal derived from wheat. There are four major flour types, hard wheat flour, whole wheat flour, soft wheat flour, and semolina. Flour is classified according to strength. Strong flours, derived from hard wheat and used mainly for bread-baking, are high in protein and elastic gluten (these include semolina, which is made from Durum wheat and used to manufacture pasta). Weak flours, derived from soft wheat, are used for biscuits and pastries and are low in protein and gluten.

Flour stream: Flour resulting from each separate process of dry milling. Flour from each point of the process has different characteristics and baking properties. In large flour mills 30 or more separate flour streams of varying composition and purity may be collected, grouped, and merchandised.

Fumigation: For purposes of this assessment, fumigation is the destruction of pests infesting grain by professional personnel, trained in the application of fumigants, i.e., chemicals that at required temperature and pressure can exist in a gaseous state in sufficient strength and quantities to be lethal to a given pest organism. Fumigants are some of the most toxic and unique pesticides, methyl bromide and hydrogen phosphide are the fumigants most commonly used on grain.

Fungus: Any of a major group (fungi) of parasitic lower plants that lack chlorophyll. Fungi include molds, rusts, mildews, and mushrooms. Aspergillus flavus is a fungus that grows on corn.

Gene: The portion of a DNA molecule that is made up of an ordered sequence of nucleotide bases and constitutes the basic functional unit of heredity.

Genetic engineering: Technologies (including recombinant DNA methods) used by scientists to isolate genes from one organism, manipulate them in the laboratory, and then insert them stably in another organism. *See* biotechnology and recombinant DNA.

Genome: A term used to refer to all the genetic material carried by a single germ cell.

Genotype: The hereditary makeup of an individual plant or animal, which, with the environment, controls the individual's characteristics.

Genotypic variability: The range of expression for a specific trait (e.g., the protein percentage in wheat, which can range from 7 to 30 percent).

Germplasm: The living stuff of the cell nucleus that determines the hereditary properties of organisms and that transmits these properties from parents to progeny. The expression is also used in a broad sense to refer to the total hereditary makeup of organisms.

Gliadin: Simple proteins obtained from alcoholic extraction of gluten from wheat or rye.

Glume: Hull or husk.

Gluten: A tenacious, elastic protein substance, found especially in wheat flour, that gives cohesiveness to dough.

Grade-determining factors: Factors selected as indicators of value and quality that help set the numerical grade of grain.

Grading: The numerical grading of grain (e.g., Number 2 Hard Red Winter wheat) according to grade-determining factors.

Grain: The seeds or fruits of various food plants, including the cereal grasses (e.g., wheat, corn, barley, oats, and rye) and other plants in commercial and statutory use (e.g., soybeans). Grain is a living organism, and as such is a perishable commodity that can be adversely affected by improper harvesting, handling, storage, and transportation.

Grain breakage: Mechanical damage to grain that results in broken grain and fine material. This is caused by the harvesting of grain that is too dry and the cumulative damage inflicted on grain during repeated handling. Grain breakage causes decreased quality, greater storage problems, and increased rates of mold and insect infestation.

Grain quality: There is no single definition of grain quality. For purposes of this assessment grain quality is defined in terms of the physical, sanitary, and intrinsic characteristics of grain. *See* intrinsic quality, physical quality, and sanitary quality.

Grain standards: Legislation (the Grain Standards Act) was passed in 1916 in an attempt to establish official standards for wheat, corn, and soybeans that would describe a level of quality and provide a basis for marketing grain. This Act remained intact until the passage of the Grain Quality Improvement Act in 1986, which provided new criteria as a basis for grain standards. Measuring grain quality is difficult to standardize and there is a lack of clear objectives, goals, and criteria concerning the form and function of such standards.

Grain storage: Grain is stored in three basic ways. Vertically, in upright metal bins or concrete silos; horizontally, in flat warehouses; and in on-ground piles. *See* vertical storage, horizontal storage, and on-ground pile storage.

Handling technologies: Technologies and equipment that are used in the receiving, drying, cleaning, storage, conveying, and transportation of grain.

Hard wheat: Wheat varieties that are high in protein (especially hard spring and winter wheats and Durum wheat).

Harvesting: The process whereby grains and oil seeds are removed from a plant, gathered, and physically removed from a field.

Hexaploid: Having six times the monoploid chromosome number. Wheat is a hexaploid plant species.

Homozygous: True breeding for a specific hereditary characteristic. A plant that breeds true for a specific characteristic (such as flower color) is called homozygous for this characteristic.

Horizontal storage: Grain storage in buildings constructed of metal, wood, or concrete, which have flat floors and are filled by means of a portable incline belt or conveyors in the roof. These storage facilities are more difficult to load, unload, aerate, and fumigate than vertical storage facilities.

Hybrid: An offspring of a cross between two genetically unlike individual plants or animals. Hybrid corn varieties have produced increased yields in some parts of the United States, and progress is being made in developing techniques for the commercial production of hybrid wheat.

Incline belt: An endless belt, used to convey grain, which is supported by rollers and driven by a shaft-mounted speed reducer motor.

Insecticides: Chemicals used to destroy insect pests. The insecticides most commonly used on grain are pyrethrins, malathion, and the more recently introduced pirimphos-methyl, chlorpyrifos-methyl, and bacillus thuringiensis (BT).

Insects: Insects create numerous problems causing loss and damage in stored grain. Grain is lost when consumed by the insects, insect wastes are left behind in the grain, and insect fragments are found in finished grain products, increased heat and moisture resulting from insect metabolic processes can lead to mold growth, and the use of insecticides can leave pesticide residues in the grain.

Intrinsic quality: Characteristics critical to the end use of grain. These are nonvisual and can only be determined by analytical tests. For example, the intrinsic quality of wheat is determined by characteristics such as protein, ash, and gluten content; the intrinsic quality of corn by its starch, protein, and oil content; and the intrinsic quality of soybeans by their protein and oil content.

Isoglucose: A sweetener and sugar substitute derived from wheat starch.

Micro-organisms: Minute, microscopic, or submicroscopic living organisms Examples are bacteria, mycoplasma, and viruses. They are parasites that gain their sustenance from the material that they grow on, such as grain.

Millfeed: The material remaining after all the usable flour is extracted from grain. The material is used by the feed industry to make animal feed and feed supplements.

Milling: A process by which grain kernel components are separated either physically or chemically, and grain is ground into flour or meal.

Mixed-flow dryers: The most prevalent type of large, continuous-flow, off-farm dryer used in countries outside the United States. In these dryers, grain is dried by a mixture of crossflow, concurrent flow, and counterflow drying processes, which dry grain more uniformly and produce a higher quality grain. These dryers are expensive to manufacture and require extensive air-pollution equipment.

Moisture: Moisture content and uniformity is a critical factor in grain quality. If grain is too wet or too dry at harvest damage occurs. Moisture also interacts with temperature and relative humidity in grain storage centers and during shipping, when too much moisture can spur mold growth, increase insect activity, and cause other quality losses.

Mold: A superficial growth produced on damp or decaying matter. Molds draw their sustenance from the material they grow on. Mold growth on grain creates damaged kernels, deposits toxic substances in the grain, and results in a loss of dry matter. As they grow, molds produce heat and moisture, which encourages their further proliferation.

Monogastric: An animal that has one digestive cavity (for example, swine, poultry, humans).

Near-infrared reflectance spectroscopy (NIRS): A new analytical technique that can determine the structure of compounds and the composition of substances by examining them with a spectroscope that is designed to operate in the infra-red region of the spectrum. One application of this technique is the measurement of moisture and protein percentages in wheat. *See* spectrophotometer.

Non-bin dryers: The most popular on-farm dryers, these are generally high-capacity, high-temperature systems, that frequently overheat and overdry the grain, causing serious deterioration in grain quality.

Non-grade-determining factors: Factors that influence the quality of grain, but which are not taken into account in the grading of grain, and which must be reported as information whenever an official inspection is made.

Off-farm dryers: High-capacity, high-temperature, commercial grain dryers that are used away from the farm. These fall into three categories, cross-flow, concurrent-flow, and mixed-flow dryers.

On-farm dryers: Grain dryers used by farmers to dry grain. At least 80 percent of the United States corn crop is dried on-farm. On-farm dryers fall into three categories, bin-dryers, non-bin dryers, and combination dryers.

On-ground pile storage: Storage of grain placed in piles directly on the ground or on pads, either covered by a tarp or left uncovered. Piles can be contained by fixed or movable sloping walls or circular rings. Grain stored by this method is difficult to load, unload, aerate, and fumigate.

Pericarp: The covering of a seed that is derived from the ovary wall.

Physical quality: Grain characteristics associated with the outward appearance of the grain kernel, including kernel size, shape, color, moisture, damage, and density.

Plant breeding: The development of plants with certain desirable characteristics. Grain breeding programs generally aim to improve yield and harvestability, increase disease resistance, and satisfy apparently desirable intrinsic quality goals.

Precleaning: The removal of foreign material such as weeds, seeds, dirt, stems, and cobs from the grain before it is dried. This results in a more uniform moisture content in the dried grain and eliminates the drying of material that detracts from grain quality. Precleaning is not generally practiced by dryer operators in the United States. *See* cleaning.

Protein: The total nitrogenous material in plant or animal substances. Proteins occur naturally and are complex combinations of amino acids.

Recombinant DNA: Techniques involving the incorporation of DNA fragments, generated with the use of restriction enzymes, into a suitable host organism. The host is then grown in a culture to produce clones with multiple copies of the incorporated DNA fragment. This and other genetic engineering techniques hold future promise for altering the genetic makeup of plants to enhance various desirable characteristics, but they are not yet widely used. *See* biotechnology and genetic engineering.

Rheology: The study of the flow of materials, particularly the plastic flow of solids.

Sanitary quality: Grain characteristics associated with cleanliness. They include the presence of foreign material that detracts from the overall value and appearance of the grain, including the presence of dust, broken grain, rodent excreta, insects, residues, fungal infection,and nonmillable matter.

Screw augur conveyor: A round tube with a continuous screw on a spiral inside. The principal means of moving grain on farms where inexpensive portable equipment is needed.

Sedimentation test: A test that measures the quality of protein content in wheat. Ground wheat is suspended in water and treated with lactic acid. The portion that settles to the bottom of a graduated cylinder within 5 minutes is the sedimentary value.

Shrink: The loss of weight in grain due to the removal of water.

Single-cross hybrid: A first generation hybrid between two selected and usually inbred lines.

Soft wheat: Varieties of wheat that contain low amounts of protein.

Sorghum: A cultivated plant derived from a genus of Old World tropical grasses, similar to Indian corn.

Soybeans: A hairy annual Asiatic legume, widely grown for its oil rich proteinaceous seeds and for forage and soil improvement. Soybeans are used mainly for oil and for high-protein meal for animal feed. The principal soybean-producing states are Illinois, Indiana, Iowa, Missouri, Mississippi, and Ohio. The United States produces 60 percent of the world supply of soybeans.

Spectrophotometer: An instrument that measures the relative intensities of light in different parts of the spectrum. *See* near-infrared spectroscopy.

Steepwater: Water used to soak corn during the wet milling process.

Stress-cracks: Cracks in the horny endosperm of corn caused by the rapid drying of kernels with heated air. Stress-cracking causes increased breakage during handling and reduces flaking grit yields.

Tempering: The addition of moisture to wheat and corn during the dry milling process to aid the removal of bran from the endosperm.

Tissue culture: A technique in which portions of a plant or an animal are grown on artificial culture medium in an organized state (e.g., as plantlets) or in an unorganized state (e.g., as callus).

Triticale: A hybrid between wheat and rye that has a high yield and a rich protein content.

Unit trains: A train of 50 or more railcars departing from the same point for the same destination with one bill of lading. This is an efficient way of transporting grain.

U.S. Grain Standards Act: This Act, administered by the FGIS, requires that uniform standards be developed and used when marketing grain. Testing is provided for, but no requirement exists as to what tests should be performed on grain moving domestically within the United States. Mandatory testing of grain for export is required.

Variety: Any of various groups of plants of less than specific rank. *See* cultivar.

Vertical Storage: The storage of grain in upright concrete silos or metal bins that can range in size from as little as 3,000 bushel farm bins to 500,000 bushel commercial bins. They are easy to load, unload, aerate, and fumigate.

Vital wheat gluten: A wheat product containing 75 to 80 percent protein, used as a flour fortifier, the product of new advances in wheat processing technologies.

Wet milling: Processes using water in which corn is tempered and steeped and converted into starches. More than half of these starches are converted into corn syrups and corn sugars. Corn oil is also extracted during starch recovery.

Wheat: Any of various grasses high in gluten that are cultivated in various temperate areas for the grain that they yield, which is used in a vast array of products. In the United States the main wheat-producing states are Kansas, Oklahoma, Texas, Nebraska, and Colorado. Hard Red Winter wheat is the main wheat variety grown in the United States.

Wheat starch: The portion of the wheat kernel remaining after the gluten has been extracted.

Appendix C

Commissioned Papers and Authors

This report was possible in part because of the valuable information and analyses contained in the background reports commissioned by OTA. These papers were reviewed and critiqued by the advisory panel, workgroups, and outside reviewers. The papers are available through the National Technical Information Service.*

The Genetics of Grain Quality

Wheat Breeding Issues Related to Grain Quality

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Molecular Biology
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Soybean Breeding and Seed Quality

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Grain Quality and Corn Breeding

A. Forrest Troyer
DeKalb-Pfizer Genetics

Technologies Affecting Quality

Effect of Harvesting Technologies on Corn and Soybean Quality

Marvin R. Paulsen
University of Illinois

Wheat Quality as Influenced by Harvesting Machinery

Mark D. Schrock
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Handling and Storage of Wheat: An Assessment of Current Technology

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The Interaction of Corn and Soybean Quality With Grain Storage

Charles R. Hurburgh
Iowa State University

Cleaning and Blending of Corn and Soybeans

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Grain Drying Technology

Fred W. Bakker-Arkema
Michigan State University

Fumigation and Other Insect Management Interventions

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Robert Davis
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Savannah, GA

Alternative Grain Transportation and Distribution Technologies and Their Impact on Grain Quality

C. Phillip Baumel
Iowa State University

Grain Quality Attributes for Corn Dry Milling

Marvin R. Paulsen
University of Illinois

Grain Attributes for the Feed Industry
Tilden W. Perry
Purdue University

Technology for the Inspection of Corn, Soybeans And Wheat
Charles R. Hurburgh
Iowa State University

Economic and Institutional Analysis

Analysis of Demand for Wheat Quality Characteristics
William W. Wilson
Jean Riepe
North Dakota State University
Paul Gallagher
Kansas State University

Farm Programs and Grain Quality
William W. Wilson
Craig Anderson
North Dakota State University
Paul Gallagher
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Effect of Domestic Regulatory Policies on U.S. Grain Technology and Quality
Rhond Rudolph Roth
Washington, DC

Analysis of the United States Grain Standards
Lowell D. Hill
University of Illinois

Major U.S. Grain Competitors

A Comparison of Quality Factors of the Argentine and United States Grain Systems
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A Comparison of Quality Factors of the French and United States Grain Systems
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*These commissioned papers will be available in spring of 1989 from the National Technical Information Service, Springfield, VA 22161, telephone (703) 487-4650.
Volume 2: Commissioned Papers
Part A: The Genetics of Grain Quality
Part B: Technologies Affecting Quality
Part C: Economic and Institutional Factors of Grain Quality
Part D: Major U.S. Grain Competitors

Appendix D

Acknowledgments

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